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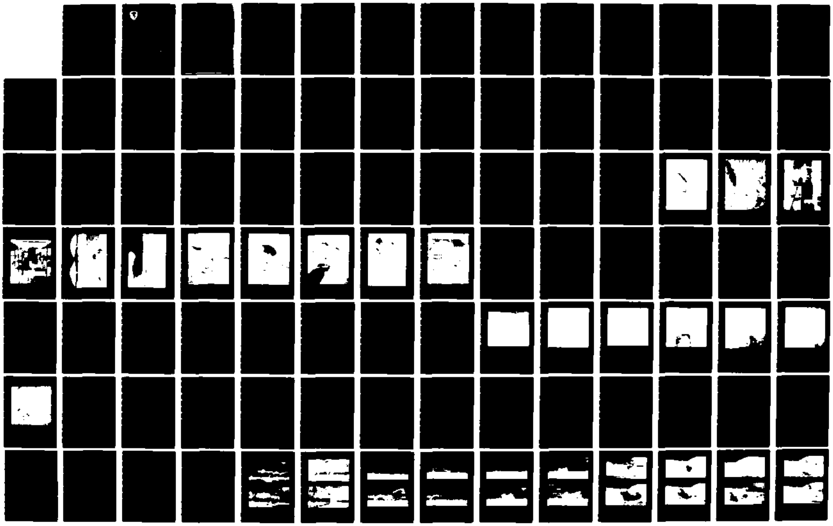

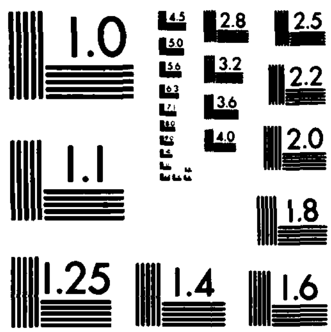

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METHODOLOGY INVESTIGATION

FINAL REPORT

ENVIRONMENTAL REALISM--BATTLEFIELD OBSCURATION IN THE TROPICS (PHASE II)

by

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DECEMBER 1982

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A joint methodology investigation between US Army Waterways Experiment Station and US Army Tropic Test Center was conducted in the humid tropics of the Republic of Panama from February through July 1982. The main objective was to determine the relationship between soil parameters and obscuration features of clouds produced by static detonations of munitions and explosives in the humid tropics during the dry season. A combined total of forty-one 15-pound TNT charges and 105- and 155-millimeter high explosive rounds

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were detonated statically in various types of vegetation at three sites, including an ocean beach site. In addition, six tube-delivered 105-millimeter, high explosive, M1 rounds were fired during the dry season and six during the wet season to collect comparison data. It was concluded that the amount of obscuration in the humid tropics is determined mainly by a combination of two factors: windspeed and soil moisture.

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FOREWORD

This cooperative research project was conducted in the Republic of Panama by the US Army Tropic Test Center (USATTC) and the US Army Waterways Experiment Station (USAWES). It was completed under the guidance of the following USATTC personnel: CPT Thomas R. Hydock, Test Officer; SSG Michael Parkhurst, Test NCO; Mr. Robert J. Fuchs, Mathematical Statistician; SFC George Hall, Explosive Handler; Mr. David Wiatt, Scientific and Technical Video Specialist; and Mr. Robert H. Johnson, Engineering Technician. The Atmospheric Sciences Laboratory (ASL) Meteorological (Met) Team (Panama) collected and recorded meteorological data during this test.

SECTION 1. SUMMARY

1.1 BACKGROUND

a. The performance of many modern weapons systems can be affected adversely by heavy concentrations of dust and smoke in the air. In recent years, a systematic effort has been underway to assess such effects, both in the field and through mathematical computer models, to meet the need for a more realistic battlefield representation. Basic computer models describing physical phenomena, such as scattering and absorption of radiation, have been applied to battlefield scenarios characterizing a wide range of conditions. The results have been used to produce parametric computer models for predicting environmental conditions in specific geographic or climatic regions. In most cases, engineering computer models, developed to describe the performance of a number of weapons systems, have, or will have, incorporated such parametric models. While these models serve the needs of the engineering community in developing and, to some extent, evaluating such weapons systems, a further step is desired. That step is to use models to determine how effective a weapons system is when actually deployed in a specific geographic/climatic area.

b. A fundamental gap must be bridged--the link between obscurant material and terrain. Much of the obscurant material on the battlefield originates in the soil and is raised by battle activity. Before this link can be understood properly, the relationship between specific combat activities and obscurant production must be described accurately. This methodology investigation was developed to supply descriptive data on obscurant production from munitions and explosives in the humid tropics. The investigation was funded jointly by USAWES and US Army Test and Evaluation Command (TECOM). USAWES independently conducted limited particle size sampling during selected detonations.

c. During July and August of 1980, USATTC investigated the battlefield obscuration characteristics of the humid tropic environment during the Republic of Panama's wet season (May through December). The report of that investigation was published in January 1981 (reference 1). The current study was conducted during the tropic dry season to document obscuration produced during the dry season (January through April).

1.2 OBJECTIVES

a. Determine the relationship between levels of soil/meteorological parameters and obscuration features of clouds produced by munitions and explosives in the humid tropic dry season.

b. For both the dry and wet seasons, determine differences in crater volumes resulting from static, above-ground 105-millimeter detonations versus tube-delivered, live-fire 105-millimeter rounds.

1.3 SUMMARY OF PROCEDURES

a. The test was conducted at Empire Range 6 (on the Pacific side of the Isthmus of Panama), and at Mindi Farm and Pina Beach (on the Atlantic side). In-place detonations of 155-millimeter rounds, 105-millimeter rounds, and 15-pound (6.8 kg) blocks of TNT were employed at Range 6 and Mindi Farm, while only TNT was used at Pina Beach. Live-fire, tube-delivered 105-millimeter trials were accomplished from Empire Range 6, with rounds bursting approximately 4,500 meters away from the firing site at Range 10.

b. At Empire Range 6, two blast areas were used. Two of these areas were chosen because each area was covered by a different grass species: _Gynerium sagittatum_ (2 to 3 meters high) and _Panicum_ sp (1 meter high).

(1) Three shots (one each of 155mm, 105mm, and TNT) were detonated statically in three different grass levels: uncut grass; grass cut to 0.3 to 0.5 meter; and bare soil cleared of all grass.

(2) The 155- and 105-millimeter munitions were set, nose down, on the surface of the soil at a 30-degree angle of attack, and detonated electrically. The TNT was placed so that the total charge detonated simultaneously.

c. The tube-delivered, live-fire trials consisted of firing six 105-millimeter high explosive (HE), M1 rounds during the dry season and six during the rainy season. Because Empire Range 6 is not an approved impact area for indirect fire, a target area was selected in an approved impact area (vicinity of Empire Range 10) with soil characteristics similiar to those of Empire Range 6. Rounds were fired using standard artillery procedures from an M102 Howitzer which was adjusted to the proper target area by trained fire support personnel. All rounds were fired approximately 4,500 meters using charge 3 to approximate the 30-degree entry angle that was used during static detonation. Bursts were dispersed by changing the azimuth on the gun to avoid the possibility of debris from adjacent bursts falling into other craters. Crater dimensions and soils data were collected after all rounds were fired.

d. Two additional static detonations, one 155-millimeter (HE), M107 projectile and one 15-pound TNT charge, were fired into a red clay soil commonly found in Panama. Because this soil type was not common to the approved firing location, bulk samples were used to fill existing craters at Empire Range 6 and were allowed to settle for 3 days before detonation.

e. At the Pina Beach site, 12 TNT charges were detonated. The charges were detonated on the ground in six different areas: white, saturated sand (shoreline); white, wet (top 2 to 3 centimeters partially dry) sand; black, wet (top 2 to 3 centimeters partially dry) sand; and three sandy soil sites, each with a different dominant plant species: _Ipomoea pes-caprae_ (morning-glory); _Hymenocallis americana_ (spider lily); and _Panicum maximum_ (2 to 3 meters high).

f. At Mindi Farm, the munitions and charges were detonated in three different levels of vegetation: Gynerium sagittatum 2 to 3 meters high, Gynerium sagittatum cut to 0.3 to 0.5 meter, and bare soil cleared of all vegetation. The explosives were set and detonated on the soil surface in the same manner as at Range 6.

g. At all sites except Range 10 (tube-delivered trials), bulk soil samples were collected before and after the detonations. The cone index (CI) was measured and moisture and density samples were collected. Crater profiles and photographs are presented in Appendix D. For all static detonations, blow-out material was collected at points 3, 6, and 9 meters from the center of the blast on the four points of the compass. Bulk soils samples and blow-out material were analyzed.

h. Still photograph and video tape records were made of all detonations at all sites (except for the tube-delivered trials). Video taping began 10 seconds before each static detonation and continued until the cloud dissipated (approximately 1 minute). Clouds were tracked by the video and still cameras during this period. Analysis of video tapes provided data on cloud obscuration in a vertical plane. Representative cloud photographs are provided in part 4 of Appendix D.

1.4 SUMMARY OF RESULTS

a. Correlation coefficients between levels of obscuration and soil parameters in the dry season are discussed and presented in Section 2 of this report. The highest and most consistent correlation observed was between soil moisture and area of obscuration.

b. Minimal obscuration occurred on the windward (Atlantic) side of the Isthmus during the dry season. Obscuration on the leeward (Pacific) side during the dry season approximated that found during the wet season (figure 1).

c. At Range 6 on the Pacific side and at Mindi Farm on the Atlantic side, craters produced in the dry season were half the volume of craters produced in the wet season. At Pina Beach, crater volumes were the same in both seasons (tables C-6 and C-7, and comparable tables in reference 1).

d. At Mindi Farm, surface soil moisture remained high during the dry season. At Range 6, soil moisture was low during the dry season.

e. At all sites, windspeeds were significantly higher during the dry season than during the wet season.

f. Grass height did not affect crater volume, but did affect obscuration. Areas of obscuration at (10 and 20 seconds after the blast) from rounds detonated in uncut grass were approximately half the size of those observed for cut grass and bare soil.

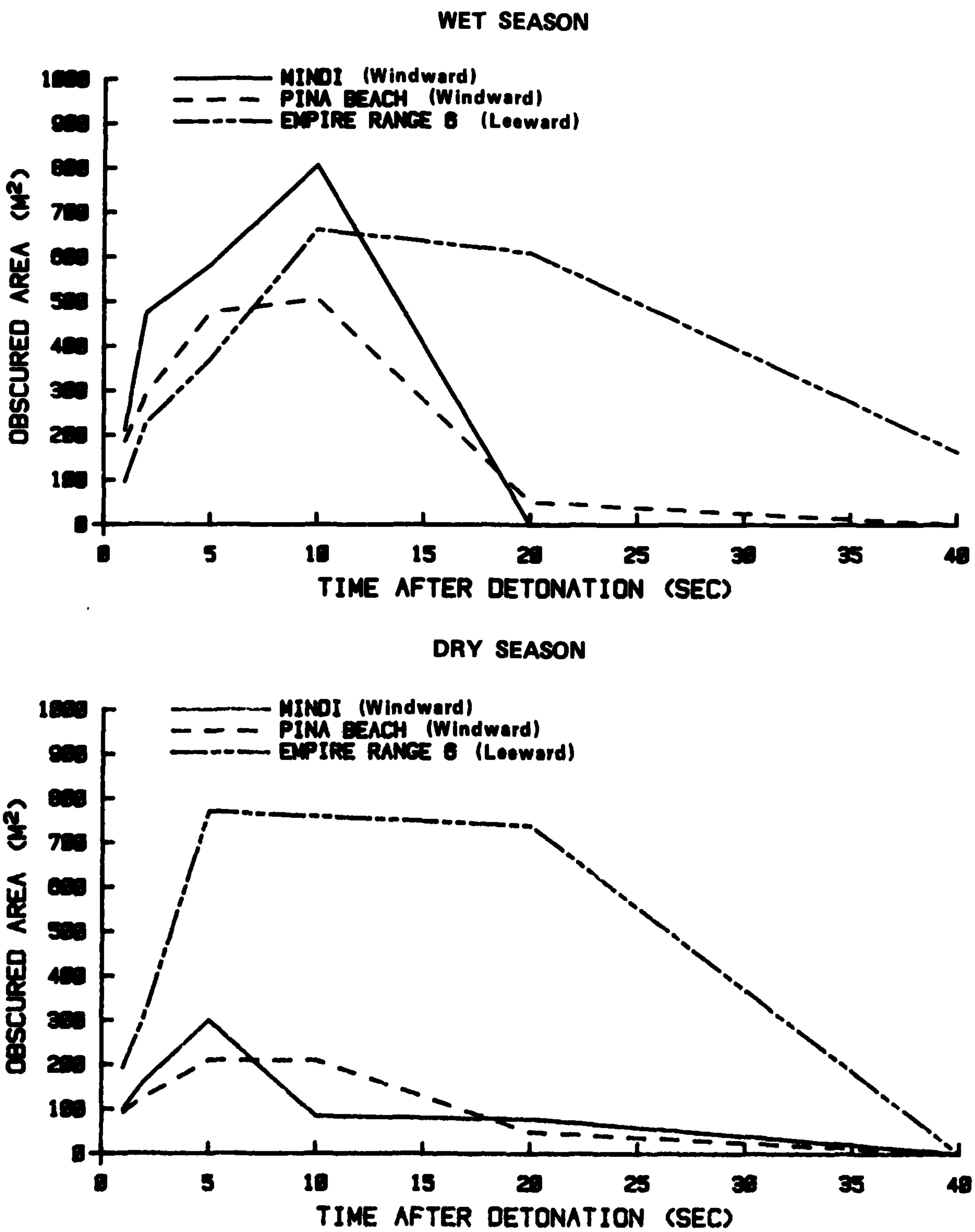


Figure 1. Obscured Area 'ersus Tim (TNT Data).

g. Mean crater volumes for tube-delivered 105-millimeter HE rounds were 0.2003 cubic meters (dry season) and 0.369 cubic meters (wet season). Mean crater volumes for statically detonated 105-millimeter HE rounds (Range 6 only) were 0.098 cubic meters (dry season) and 0.209 cubic meters (wet season).

1.5 ANALYSIS

a. Of all the soil/meteorological parameters investigated in this study, soil moisture showed the strongest and most consistent correlation with area of obscuration during the dry season. Windspeed also affected area of obscuration, but results from both the wet and dry season studies must be evaluated together to see this effect because windspeeds are fairly constant within each season--low during the wet season and high during the dry season. Analysis of obscuration data, windspeeds, and soil moistures showed that, in spite of comparable soil moistures, there was significantly greater obscuration at Mindi Farm during the wet season when the winds were low as compared to the dry season when winds were high. During the dry season, obscuration at Range 6, where the soil moisture was low, was significantly greater than obscuration at Mindi Farm where the soil moisture was high, in spite of comparable windspeeds. During the dry season, dust contributed to the total obscuration only at Range 6. Obscuration at sites where soil moistures were high was caused primarily by smoke generated from the TNT and munition charges. However, dry season obscuration at Range 6 was not significantly greater than wet season obscuration for more than 5 seconds after the blast because the strong winds tended to dissipate the dust and smoke rapidly.

b. Analyses of variance and analyses of covariance (with surface moisture as the covariate) detected significantly larger crater volumes from tube-delivered 105-millimeter HE rounds than from statically detonated HE rounds for both dry season and wet season.

c. Analyses of variance computed to evaluate the effect of grass heights on obscuration did not detect significant differences at the α=.05 level. However, inspection of the means shows that the areas of obscuration at 10 and 20 seconds after blasts in uncut grass were approximately half the size of those observed for cut grass and bare soil. A similar effect of grass height on obscuration occurred in the wet season (reference 1).

1.6 CONCLUSIONS

a. The amount of obscuration produced by detonating munitions and explosives in the humid tropics depended mainly on the levels of two parameters: soil moisture and windspeed.

b. Crater volumes from tube-delivered 105-millimeter HE rounds were significantly larger than those from statically detonated 105-millimeter HE rounds.

c. Grass height influenced the size of clouds produced. Munitions produced smaller clouds in tall grass than in cut grass or bare soil.

1.7 RECOMMENDATION

Because obscuration produced by detonating munitions and explosives in the humid tropics is minimal, additional studies of the relationship between soil/meteorological parameters and obscuration are not recommended.

SECTION 2. DETAILS OF INVESTIGATION

2.1 MATERIALS, METHODS, AND RESULTS

2.1.1 Surface and Soil Types. For this study, test shots were detonated during the dry season (February and March) at three sites--Empire Range 6, Mindi Farm, and Pina Beach (figure 2). A site description for each crater is included in table C-1. The three sites differed in surface and soil types, as described below. In addition, USATTC completed two separate tube-delivered live-fire exercises. Twelve 105-millimeter (HE) M1 cartridges were fired from an M102 Howitzer (105mm) at Range 6 and detonated in an impact area at Range 10, approximately 4,500 meters away from the firing position. The first live-fire exercise (six rounds) was conducted during the dry season (March), and the second firing exercise (six rounds) was conducted during the wet season (July). Trained fire support personnel used standard field artillery procedures to fire the Howitzer and to adjust the gun to the proper impact point. Bursts were dispersed by changing the azimuth on the gun to prevent debris from falling into adjacent craters. Firing data were computed to allow the entry angle (angle of fall) of the projectile to approximate, as closely as possible, the 30-degree incline used for the static detonation of the same round type. After all rounds had been fired, craters were located and measured using the same procedures used for measuring the craters from static detonations. The impact area (vicinity of Range 10) was selected because it had vegetation and soil characteristics similar to those found on Range 6.

a. Surface Types

(1) Gynerium sagittatum (Range 6 and Mindi Farm): The grass was approximately 3 meters high at Range 6 and 2 to 3 meters high at Mindi Farm. The stem density was 60 to 70 stems-per-square-meter, with stem size ranging from 3 to 13 millimeters in diameter. Root depth was approximately 30 centimeters. Distance between grass clumps averaged 30 to 60 centimeters.

(2) Cut Gynerium sagittatum (Range 6 and Mindi Farm): The description in subparagraph 2.1.1a(1), above, applies, except that grass was cut to 0.3 to 0.5 meter.

(3) Bare, cleared soil (Range 6 and Mindi Farm): To produce this type of surface, all grass and vegetation were cleared from the ground for an area 10 meters in diameter around each selected blast site using machetes and rakes.

(4) Panicum sp (Range 6): The grass was approximately 1 meter high, with a stem density of 90 to 100 stems-per-square-meter. Stem size ranged from 1.6 to 6 millimeters in diameter. Root depth was approximately 15 centimeters. Distance between grass clumps averaged 46 to 77 centimeters.

(5) Cut Panicum (Range 6): The description in subparagraph 2.1.1a(4), above, applies, except that grass was cut to 0.3 meter.

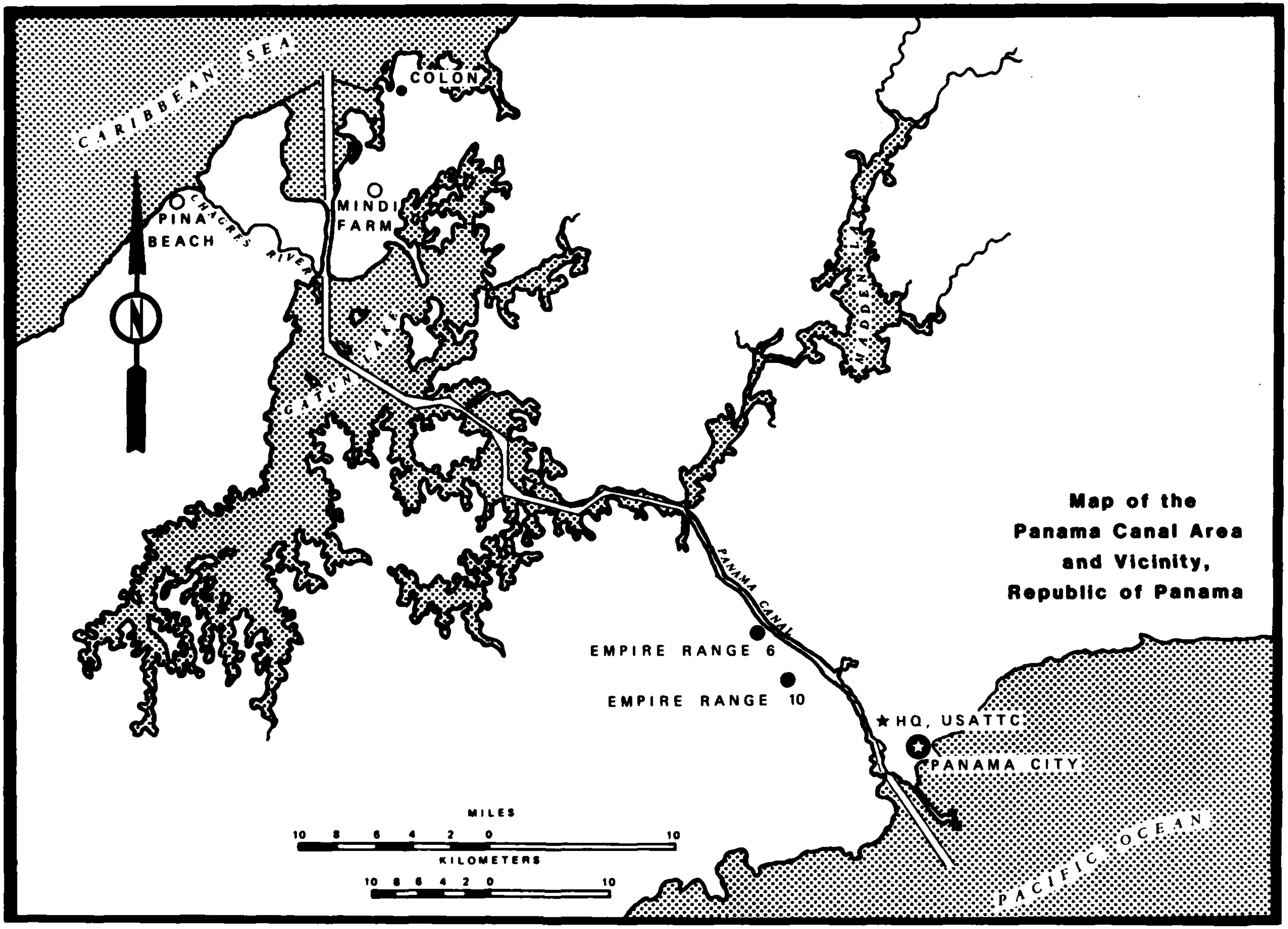


Figure 2. Location of the Three Test Sites--Empire Ranges 6 and 10, Mindi Farm, and Pina Beach.

(6) White, saturated sand (Pina Beach): The blast site was located on the shoreline.

(7) White, wet sand (Pina Beach): The blast site was located on the beach. The top 2 to 3 centimeters of sand were partially dried by sun and wind.

(8) Black, wet sand (Pina Beach): The blast site was located on the beach. The top 2 to 3 centimeters of sand were partially dried by sun and wind.

(9) Ipomoea pes-caprae (Pina Beach): The blast site consisted of sandy soil with small, leafy, ground vines (morning glories) over approximately 30 percent of the soil.

(10) Panicum maximum (Pina Beach): The blast site consisted of sandy soil with grass approximately 2 to 3 meters tall. Density was 70 to 80 stems-per-square-meter. Stem size ranged from 3 to 9 millimeters in diameter. Root depth was approximately 20 centimeters. Distance between grass clumps averaged 0.3 to 0.5 meter.

(11) Hymenocallis americana (Pina Beach): The blast site consisted of sandy soil with vegetation (spider lily) about 0.5 meter tall over 80 percent of the ground surface. Root depth was approximately 15 centimeters. Stem diameters ranged from 13 to 40 millimeters.

b. Soil Types (soil was too firm to obtain samples for remolding tests)

(1) Empire Ranges 6 and 10: The blast site consisted of relatively undisturbed lateritic, silty clay soil. From the available evidence and technology, it cannot be determined if Empire Ranges 6 and 10 are undisturbed land or fill from the construction of the Panama Canal. However, the soil has been in place for at least 60 years. Homogeneous soil with rocks, ranging in size from small gravel to 2 feet (0.6 m) in diameter, is found in both locations. At Range 6, CI readings [subparagraph 2.1.4b(1)(c)] indicated that the probable fill area had been compacted (primarily by rainfall) to CI values similar in magnitude to the perimeter area. In some cases, CI readings were erratic because the cone penetrometer struck and slipped off rocks. Although the probable fill area had a rock density approximately twice that of the perimeter area, both areas had an equivalent soil strength. Results of a combined mechanical analysis of four soil samples from Range 6 are presented in figure 2 of the previous report (reference 1).

(2) Mindi Farm: The blast site consisted primarily of silt with some fine sand and traces of clay. The site was situated on top of a hill in rolling terrain. The ground surface was relatively smooth, and the high position and slope promoted rapid drainage. Results of a combined mechanical analysis of four soil samples from Mindi Farm are presented in figure 3 of the previous report (reference 1).

(3) Pina Beach: The blast site consisted of fine coastal sands and silty sands with traces of gravel. The site was situated on a sandy beach on the Atlantic side of the Isthmus, approximately 1 kilometer southwest of the mouth of the Chagres River. Results of a combined mechanical analysis of two soil samples from Pina Beach are presented in figure 4 of the previous report (reference 1).

2.1.2 Munitions and Charges

a. The types of detonation charges included 155-millimeter (HE) M107 rounds; 105-millimeter (HE) M1 rounds; and 15-pound (6.8 kg) charges of TNT consisting of 1-pound blocks taped together. The 155- and 105-millimeter HE rounds were placed on wooden stands angled at 30 degrees from the ground (figure B-1). This configuration placed the rounds at an angle of ground entry similar to a round fired by a field artillery unit. TNT charges were placed directly on the ground for all detonations (figure B-2). All explosives were dual-primed with electric blasting caps as the primary system, and a 10-minute time fuze as a back-up.

b. Tube delivered 105-millimeter (HE) M1 rounds were fired using computed data that allowed the projectile to have an entry angle (angle of fall) of approximately 30 degrees from the ground. All rounds were fired approximately 4,500 meters with a quadrant elevation of approximately 515 mils using charge 3.

c. To evaluate the obscuration features of a red clay soil commonly found in Panama, two additional static detonations (a 155-mm HE projectile and a 15-lb TNT charge) were performed. However, the red clay was not found on any of the approved firing ranges or impact areas. Therefore, 3 days before the detonations, bulk samples of red clay (approximately 0.5 m^3 each) were used to fill craters left from a previous test. The soil was packed down by driving a pick-up truck over the fresh fill.

2.1.3 Blast Site Configurations

a. Empire Range 6 (figure 3). The blast observation post (OP) and camera position A at Range 6 were located approximately 450 meters from the blast areas. Test personnel were sheltered behind 1.3-centimeter steel blast shields or earth berms for safety. The munitions were positioned pointing away from the OP at a 45-degree angle. A second unmanned remote camera (camera position B) was located approximately 350 meters and 30 degrees out from the manned OP.

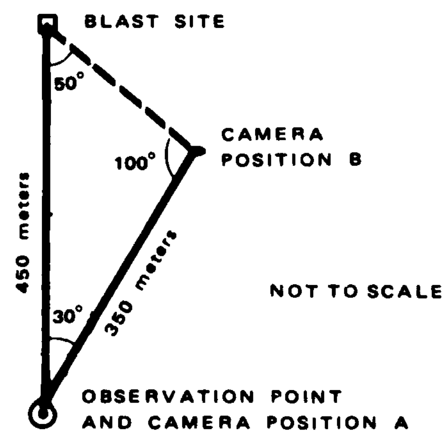


Figure 3. Observation Point and Camera Positions at Empire Range 6.

b. Pina Beach. The Pina Beach OP was located approximately 350 meters from the blast areas.

c. Mindi Farm. The OP at Mindi Farm was located approximately 400 meters from the blast areas.

2.1.4 Data Acquisition

a. Photographic Data

(1) At each blast site, a video tape camera and a 35-millimeter still camera were colocated at the OP camera position A to record each blast. The still camera was synchronized to expose one frame upon detonation and one every 10 seconds after at Mindi Farm, and one every 5 seconds after at Pina Beach and Range 6, until the cloud dissipated. Video tape coverage began 10 seconds before detonation and continued until the cloud dissipated. Cameras tracked the cloud during this period. At Range 6, a second video camera (camera position B) was operated remotely. Vertical and horizontal scale references (survey-type rods marked at 1-foot (0.3 m) increments) were positioned 25 feet (7.6 m) in front of each camera each test day. After the image was recorded, the scales were removed. Because the distance to each blast site was known, the scale reference could be projected mathematically for measurement at the place of detonation. The area of obscuration and the cloud center coordinates were digitized at 1-, 2-, 5-, 10-, 20-, and 40-second intervals following each detonation. A Hewlitt Packard (HP) 9830 computer was interfaced with the video display unit to digitize the cloud data. Durand's rule (reference 2) was used to compute the area of the obscuration. Cloud areas through which jungle or background targets were visible were not included in the obscured area computations. Cloud growth data computed from video tapes are presented in table C-2.

(2) Two camera positions were used at Range 6. Camera position A contained video and 35-millimeter still cameras. Because of the surface danger area of 155-millimeter (HE) M107 rounds, the video and still cameras were mounted on a single tripod with a remotely operated motorized head to allow tracking of the cloud after detonation. The video camera was hard-wired to the recording site. The cameras were stationed on a tower section erected on a dirt berm at Empire Range 6 (figure B-3), approximately 30 feet (9 m) above ground level. A second camera position (camera position B) was located along the azimuth of 313.5 degrees (magnetic), approximately 1,140 feet (347 m) from camera A. This single video color camera, which was installed on a camera blast shield (figure B-4) approximately 6 feet (2 m) above ground level, was used to obtain a second cross-sectioned view of the cloud. Images from camera B were transmitted by infrared laser to the recording site.

(3) At Pina Beach and Mindi Farm, the cameras were mounted on tripods approximately 5 feet (1.5 m) off the ground at the OP (figure B-5).

(4) Black and white background targets (0.6 m by 1.2 m) were placed on poles 10 to 15 meters apart (figure B-6). These targets were used to evaluate cloud opacity.

(5) Directions and distances from the OPs to each event blast site were measured using a DM-60 Cubitape device and surveyor's transit.

b. Surface Composition

(1) Specialized instrumentation and procedures used to evaluate soil strength are described below:

(a) Cone penetrometer (figure B-7): A hand-operated field instrument used to obtain an index of soil shear strength at prescribed depths. The cone penetrometer consists of a 30-degree cone with a 322.6-square-millimeter base mounted on one end of a shaft 9.5 millimeters in diameter, and a proving ring with dial gage and handle mounted on the other end. The force-per-unit area required to penetrate the soil vertically is indicated on the dial inside the proving ring, and can be read while the cone is being forced into the ground by hand at a rate of 1.8 meters-per-minute.

(b) Trafficability sampler (figure B-8): A piston-type sampler instrument used to obtain soft soil samples.

(c) CI reading: A measurement of soil strength (shearing resistance) obtained with the cone penetrometer. For this test, measurements were taken at the surface and at 1-inch (2.5 cm) vertical increments, to a depth of 6 inches (15.2 cm); then at 3-inch (7.6 cm) vertical increments to a depth of 18 inches (45.7 cm); and finally at a depth of 24 inches (61.0 cm), or until the soil strength exceeded the capacity of the instrument. Fifteen sets of readings were taken and averaged for each crater site: five sets on the original surface before the blast, five sets on the rim of the crater after the blast, and five sets at the bottom of the crater. Means of CI readings, by crater and depth, are presented in table C-3. No CI readings were taken from the indirect fire rounds at Range 10.

(2) Moisture content and density: Two moisture samples were taken from each crater site, one at the 0- to 3-inch (0 to 7.6 cm) depth and one at the bottom of the crater. (This depth varied depending on the size of blast, soil strength, and other parameters.) One density sample was taken at each crater site, also at the 0- to 3-inch (0 to 7.6 cm) depth. These data are included in table C-3.

(3) Bulk samples of 2 to 3 kilograms were taken at each blast point for laboratory analysis and identification by soil type according to the Unified Soil Classification System (USCS, reference 3). One sample was taken before the blast from the surface layer (usually 0 to 10 cm deep) at a point beyond the expected crater rim. (When it was necessary to take the sample closer to the blast point, the resulting hole was refilled with similar soil.) After the blast, another sample was taken from the bottom of the crater floor.

When bulk samples were taken, they were sealed immediately in plastic or moisture-proof containers and stored for transport to the laboratory. The data resulting from these procedures are listed in table C-4. All tube-delivered trial soil samples were taken after all rounds were fired.

(4) To collect blow-out material from the detonations, sample boards (0.6 x 1.2 m) were placed on the four points of the compass at 3-, 6-, and 9-meter intervals from center of blast. These boards were secured to the ground by 18-inch (45.7 cm) engineer drift pins. After the blast, the debris was collected from each set of equidistant boards (figure B-9), sealed in plastic bags (keeping all 3-, 6-, and 9-meter material separated), and transported back to the laboratory for weighing. Grass and soil samples were weighed first together and then separately. The data resulting from analysis of blow-out material (i.e., material weight) are shown in table C-5. No blow-out material was collected after tube delivered trials.

c. Crater measurements

(1) Symmetric craters: The diameters of these craters were measured by laying a survey rod across the apparent center of the crater at the original ground surface (figure D-1). Vertical distances (from the rod to the crater floor) were recorded at 10-centimeter increments. Measurements were made as the craters appeared after the blast, with some loose material (fallback) in the crater (figure B-10). In a few cases, loose material was scooped out (after the initial measurements) and the true craters were measured to determine the amount of fallback material.

(2) Asymmetric craters: The above-mentioned procedure was used to measure the vertical distance along the long axis of the crater. Additionally, measurements were recorded from an axis perpendicular to the first axis (figure D-1).

(3) Crater profiles, representative with/without fallback comparisons, and selected photographs are presented in Appendix D.

(4) Crater calculations. Crater volumes were computed in accordance with draft Test Operations Procedure (TOP) 4-2-830 (reference 4), and are included in table C-1.

d. Meteorological Data. Personnel from the ASL Met Team (Panama) recorded meteorological data at the blast site and the OP for each trial. Windspeed, wind direction, and temperatures were recorded for each detonation at 1-, 2-, and 4-meter heights above ground level approximately 60 meters from the blast site (figure B-11). However, windspeeds and wind directions were highly variable and the actual values that affected the cloud may differ from those recorded. For those trials detonated in high grass, temperatures were recorded at 1 and 2 meter heights in the exact blast location 10 minutes before detonation. Barometric pressure, relative humidity, and rainfall were obtained at the OP location for each detonation. Rain gages were emplaced 24 hours before detonation. Meteorological data are included in table C-1. No

meterological data were recorded during tube-delivered trials because obscuration data were not recorded.

e. Obscuration measurements. Transmissometers and Knowlenberg counters were called for by the Methodology Investigation Plan (reference 5). However, ASL was not able to provide the equipment and personnel required to record these data during the time frame of the investigation.

2.2 ANALYSIS

a. The data collected during this test were analyzed statistically at USATTC with an IBM 4331 computer and the Statistical Analysis System (SAS). Means were compared using analysis of variance and general linear model techniques. The variable selection procedure used in the stepwise multivariate regression was the maximum R^2 improvement technique (reference 6). Throughout this report, "not statistically significant" means not significant at the α=.05 level. For analysis purposes, only obscuration areas from camera A were included. The limited data available from camera B (range 6 only) are presented in table C-2.

b. Matrices of Pearson product-moment correlation coefficients between cloud/crater variables and soil/meteorological variables are presented for TNT, 105-, and 155-millimeter munitions in tables C-6 through C-8, respectively.

c. Mean crater volumes from tube-delivered 105-millimeter rounds were significantly larger than mean volumes from statically detonated rounds. Comparative data from tube-delivered and static firings are presented in table 1. As shown in table 1, dry season soil conditions were similar for tube-delivered and static rounds except for a slight difference in surface moisture. Because of this slight, but statistically significant, difference in soil moisture between Ranges 10 and 6, analyses of covariance were computed to adjust for surface moisture. The adjusted crater volumes also were statistically larger for tube-delivered rounds during both the dry and wet seasons.

d. To compare obscured areas produced at the three main test sites, only data gathered from TNT rounds were analyzed because only TNT was used at all three sites. The means presented in table 2 show that the crater volumes at Range 6 were smaller than the crater volumes at the other two sites. The crater volumes for both Mindi Farm and Range 6 were approximately half the crater volumes during wet season, as presented in the previous report. On Range 6, this difference in crater volumes resulted because the ground was much drier and harder at all layers than during wet season, as the cone indices show. At Mindi Farm, on the Atlantic side of the Isthmus where the dry season is much less severe, the surface layer (0 - 50 mm) of soil was only slightly drier and harder than during the wet season, but the soil was considerably drier and harder at layers of 100 millimeters or more. Soil conditions and crater volumes at Pina Beach were comparable to wet season levels. Measured windspeeds were much higher in the dry season than in the

TABLE 1. COMPARISON OF DATA FROM TUBE-DELIVERED VERSUS STATIC FIRINGS

(105-mm rounds only)

Variable	Tube Delivered (Range 10) Dry Season (N=6)	Tube Delivered (Range 10) Wet Season (N=6)	Static Firing (Range 6) Dry Season (N=6)	Static Firing (Range 6) Wet Season (N=14)	Probability a/	Probability b/
Crater Volume (m^3)	0.200	0.369	0.098	0.209	<.001	<.05
Surface Moisture Content (%)	22.3	53.6	16.0	37.8	<.001	<.05
Crater Volume Adjusted for Surface Moisture (m^3) c/	0.209	0.335	0.088	0.223	--	<.05
Density Wet (kg/m^3)	1174	1460	1260	0.223	<.05	NS
Density Dry (kg/m^3)	960	965	1088	1132	NS	NS
Surface Layer (%)						
Gravels	3	1	5	8	NS	NS
Sands	27	34	27	21	NS	NS
Silts	48	40	44	54	NS	NS
Clays	22	24	2[illegible]	17	NS	NS
Fines	70	65	68	71	NS	NS
Liquid Limit	62	53	58	56	NS	NS
Plastic Limit	38	38	38	37	NS	NS
Plastic Index	24	14	20	19	NS	NS

NS = Not sufficient at the α=.05 level.
a/ Probability associated with a Student's t-test of Dry vs Wet Season (tube-delivered) data.
b/ Probability associated with a Student's t-test of Tube-Delivered vs Static Firings (dry season only) data.
c/ Analyses of covariance were used to adjust crater volumes to the same surface moisture.

TABLE 2. MEANS AND SIGNIFICANCE LEVEL OF SOIL AND CLOUD DATA

(For TNT Only)

Variable	SITE Mindi	Pina	Range 6	Significance
Number of Craters	3	12	6	--
Crater Volume (m^3)	0.265	0.314	0.115	<.01
Crater Depth (m)	0.413	0.319	0.253	<.05
Obscured Area (m^2)				
at 1 second	100	94	194	<.05
at 2 seconds	163	128	308	<.01
at 5 seconds	300	210	771	<.001
at 10 seconds	84	210	760	<.01
at 20 seconds	78	48	739	NS
Material Weight (g)				
at 3 meters	2,995	2,632	1,214	NS
at 6 meters	718	501	487	NS
at 9 meters	236	182	180	NS
Moisture Content Surface (%)	68.4	7.4	14.0	<.001
Moisture Content Bottom (%)	51.0	7.5	20.9	<.001
Density Dry (kg/m^3)	838	1,523	1,105	<.001
Density Wet (kg/m^3)	1,408	1,630	1,258	<.05
Fines (%)				
0- to 152-mm Soil Layer	64	12	66	<.001
Bottom of Crater	65	16	64	<.001
Gravel 0-152mm Soil Layer (%)	0	2	7	<.001
Sand 0-152mm Soil Layer (%)	36	86	27	<.001
Silt 0-152mm Soil Layer (%)	49	10	52	<.001
Clay 0-152mm Soil Layer (%)	15	2	14	<.001
Atterburg Limits				
Liquid Limit				
0- to 152-mm Soil Layer	66.7	--	52.8	NS
Bottom of Crater	55.7	--	54.5	NS
Plastic Limit				
0- to 152-mm Soil Layer	47.7	--	36.8	<.05
Bottom of Crater	55.7	--	54.4	NS

Table 2 (cont)

Variable	Mindi	Pina	Range 6	Significance
	SITE			
Plastic Index				
0- to 152-mm Soil Layer	15.0	--	16.0	NS
Bottom of Crater	13.0	--	17.2	NS
Cone Index (kg/cm^2)				
Surface (Before Detonation)				
Surface Layer	4.9	0.9	15.7	<.001
51-mm Layer	11.0	4.4	41.5	<.001
102-mm Layer	14.4	7.7	52.7	<.001
Rim (After Detonation)				
Surface Layer	4.8	0.3	14.3	<.001
51-mm Layer	10.0	2.3	33.3	<.001
102-mm Layer	13.1	4.0	50.8	<.001
Bottom of Crater				
Surface Layer	3.0	1.0	11.6	<.001
51-mm Layer	6.0	7.1	33.9	<.001
102-mm Layer	9.4	12.6	46.9	<.001
Meteorological Data				
Temperature (°C)				
at 1 meter	28.5	30.1	32.0	<.005
at 2 meters	27.8	28.7	31.1	<.001
at 4 meters	27.6	27.9	31.0	<.001
Relative Humidity (%)	71	70	52	<.001
Wind Speed (knots)				
at 1 meter	4.6	7.0	7.1	<.01
at 2 meters	6.1	9.8	10.1	<.05
at 4 meters	7.8	12.0	10.1	<.01

NS = Not Significant

wet season, which is typical for the Isthmus of Panama. The overall effect of soil dryness and windspeed on obscuration can be seen by comparing obscuration curves for the dry season to obscuration curves for the wet season (figure 1). From figure 1 it can be seen that at Mindi Farm and Pina Beach, where surface soil moistures were similar to wet season values and winds were much stronger, obscuration was minimal. Surface moisture content at these two sites was too high to form dust. Strong winds dissipated the smoke quickly. However, at Range 6, where the soil was very dry, considerable dust was raised, but dissipated after 20 seconds because of strong winds. The resulting obscuration was only slightly greater in area, and fell off only slightly sooner than observed during the wet season. Student's t-tests were computed on surface moisture, windspeeds, and areas of obscuration to evaluate differences between dry and wet seasons (at each site), and between sites (dry and wet seasons separately). The means and probability levels associated with these tests are presented in tables 3 and 4. These statistical analyses support the above discussions. Specifically, it is shown that at Mindi Farm there was significantly less obscuration in the dry season with strong winds, even though the soil was slightly drier, while at Range 6 during the dry season when the soil was much drier, the obscuration was significantly greater, even though the windspeeds were slightly higher. At Range 6, the obscuration was similar for the dry and wet seasons where the effects of the dry soil were counter-balanced by the effects of high winds. Maximum obscuration in the tropics would be attained when the soil is dry and the winds are low, but this combination of factors is rarely found. Dry season on the leeward (Pacific) side of the Isthmus is accompanied by high winds and low surface soil moisture. On the windward (Atlantic) side of the Isthmus, even in dry season, sufficient rainfall keeps the soil surface moisture content high. This wet soil, accompanied by high winds, kept obscuration to a minimum.

e. In comparing the effects of three munition types and levels of grass (uncut grass, cut grass, and bare soil), only data from Mindi Farm and Empire Range 6 were analyzed. Results (main effect probability levels) from the two-way analyses of variance are presented in tables 5 and 6. While these results show that the 155-millimeter ammunition created larger craters and produced more blowout material than TNT and 105-millimeter rounds, TNT produced the largest obscured areas. This greater obscured area can be attributed to the black smoke characteristic of TNT detonations. By comparing the obscuration curves for dry season to the obscuration curves for wet season (figure 4), it can be seen that the 155-millimeter rounds produced more obscuration in the dry season than in the wet season. This was because fragmentation raised more dust in dry soil. While the means for the different grass levels did not differ significantly at the $\alpha=.05$ level (the variability was large and the sample size small), the obscured area at 10 and 20 seconds after the blast was twice as large for rounds fired in bare soil and cut grass when compared to rounds fired in high grass. A similar effect was reported in the wet season study (reference 1).

TABLE 3. COMPARISON OF MEAN AREAS OF OBSCURATION IN WET AND DRY SEASON, BY SITE

Variable	Mindi Farm Season Dry	Mindi Farm Season Wet	Mindi Farm Probability	Range 6 Season Dry	Range 6 Season Wet	Range 6 Probability
Surface Moisture (%)	60.0	70.6	<.01	15.3	37.6	<.001
Windspeed (knots)	6.7	3.9	<.025	9.4	3.7	<.001
Obscured Area (m^2)						
at 2 seconds	128	354	<.025	231	166	NS
at 5 seconds	155	374	NS	506	249	<.01
at 10 seconds	42	482	<.05	526	374	NS
at 20 seconds	8	0	NS	512	274	NS

TABLE 4. COMPARISON OF MEAN AREAS OF OBSCURATION: MINDI FARM VERSUS RANGE 6, BY SEASON

Variable	Dry Season Mindi	Dry Season Range 6	Dry Season Probability	Wet Season Mindi	Wet Season Range 6	Wet Season Probability
Surface Moisture(%)	60.0	15.3	<.001	70.6	37.6	<.001
Windspeed (knots)	6.7	9.4	<.025	3.9	3.7	NS
Obscured Area (m^2)						
at 2 seconds	128	231	<.01	354	167	NS
at 5 seconds	155	506	<.001	374	249	NS
at 10 seconds	42	526	<.005	482	374	NS
at 20 seconds	28	512	<.01	0	274	<.01

TABLE 5. MEANS AND SIGNIFICANCE LEVELS OF CRATER AND CLOUD DATA FROM MINDI FARM AND RANGE 6, BY MUNITIONS TYPE

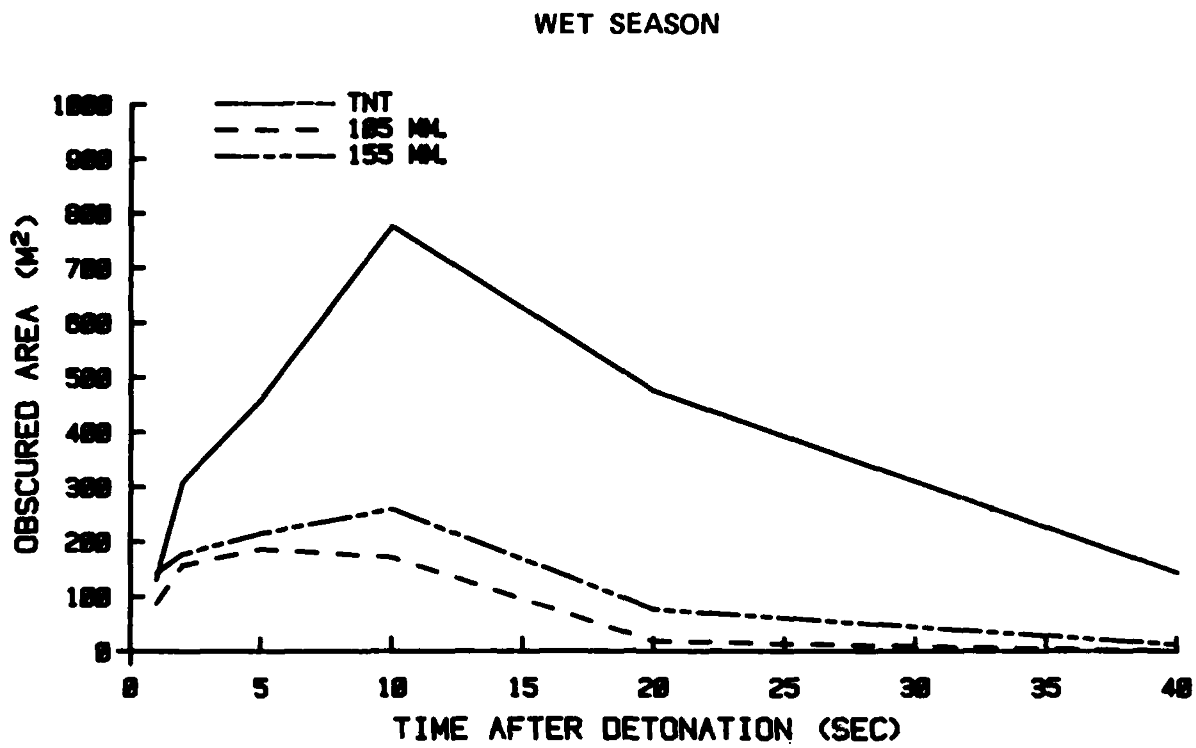
Munition	Number of Craters	Crater Volume	Obscured Area Seconds After Detonation 1	2	5	10	20	Weight of Blow-out Material 3m	6m	9m
		(m^3)			(m^2)				(g)	
TNT	9	0.165	162	260	614	534	518	1,808	564	198
105mm	9	0.128	89	122	224	227	70	1,421	416	202
155mm	8	0.290	140	206	306	308	458	2,432	753	369
Significance	--	<.01	NS	<.05	<.01	NS	NS	NS	<.05	<.001

NS = Not Significant.

TABLE 6. MEANS AND SIGNIFICANCE LEVELS OF CRATER AND CLOUD DATA FROM MINDI FARM AND RANGE 6, BY VEGETATION LEVEL

Grass Level	Number of Craters	Crater Volume	Obscured Area Seconds After Detonation					Weight of Blow-out Material		
			1	2	5	10	20	3m	6m	9m
		(m^3)	(m^2)					(g)		
Bare Soil	9	0.194	101	154	327	394	355	1,669	513	230
Cut Grass	9	0.216	168	242	473	519	452	2,375	583	246
Uncut Grass	9	0.174	118	186	346	176	228	1,616	636	293
Significance	--	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Not Significant.



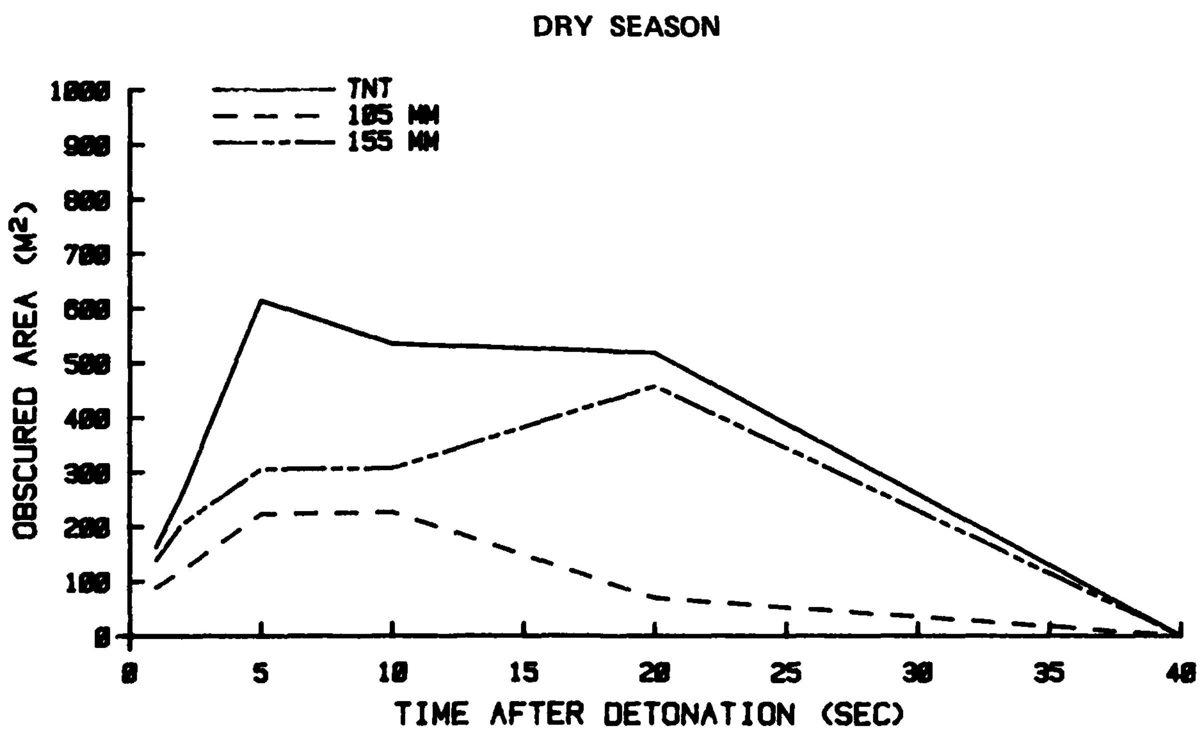


Figure 4. Obscured Area Versus Time (Mindi Farm and Empire Range 6).

SECTION 3. APPENDIXES

APPENDIX A. TEST DIRECTIVE AND METHODOLOGY INVESTIGATION PROPOSAL

(COPY) Mrs. Testerman/brt/283-3677

DEPARTMENT OF THE ARMY S: 18 Nov 81
HEADQUARTERS, US ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005

DRSTE-AD-M 26 Oct 1981

SUBJECT: Directive, Environmental Realism - Battlefield Obscuration (Phase II) TRMS No. 7-CO-RD2-TT1-001

Commander
US Army Tropic Test Center
ATTN: STETC-TD-M
APO Miami 34004

1. Reference TECOM Regulation 70-12, dated 1 June 1973.

2. This letter and attached STE Forms 1188 and 1189 (Incl 1) constitute a directive for the subject investigation under the TECOM Methodology Improvement Program 1T665702D625.

3. The MIP at Inclosure 2 is the basis for headquarters approval of the subject investigation.

4. Special Instructions:

a. All reporting will be in consonance with paragraph 9 of the reference. The final report, when applicable, will be submitted to this headquarters, ATTN: DRSTE-AD-M, in consonance with Test Event 52, STE Form 1189.

b. Recommendations of new TOPs or revisions to existing TOPs will be included as part of the recommendation section of the final report. Final decision on the scope of the TOP effort will be made by this headquarters as a part of the report approval process.

c. The utilization of the funds provided to support the final investigation is governed by the rules of incremental funding.

d. The addressee will determine whether any classified information is involved and will assure that proper security measures are taken when appropriate.

e. Upon receipt of this directive, test milestone schedules will be immediately reviewed in light of known other workload and projected available resources, in accordance with provisions of paragraph 1-3 to TECOM Regulation 70-8. If rescheduling is necessary, this headquarters, ATTN: DRSTE-TO-O, will be notified by 1st Indorsement, not later than 18 Nov 81. If schedules can be met, a P8 entry will be made directly into TRMS master file by that date.

f. The Methodology Improvement Division point of contact is Mr. Warren M. Baity, ATTN: DRSTE-AD-M, AUTOVON 283-2375/2170.

FOR THE COMMANDER:

2 Incl
as

/s/Grover H. Shelton
/t/GROVER H. SHELTON
C, Meth Imprv Div
Analysis Directorate

(END COPY)
(only Incl 2 is included)

(COPY)

February 1981

1. TITLE. Environmental Realism--Battlefield Obscuration (Phase II)

2. CATEGORY. Environmental Testing

3. INSTALLATIONS. US Army Tropic Test Center
APO Miami 34004

US Army Engineer Waterways Experiment Station
Vicksburg, MS 39180

4. PRINCIPAL INVESTIGATORS. CPT Marie Martinucci
Materiel Test Division
AUTOVON: 313-285-4101

Mr. James Mason
AUTOVON: 601-634-2601

5. STATEMENT OF THE PROBLEM. A fundamental gap in knowledge exists in the relationship between obscurant production during combat activities and the type and condition of soils encountered in heavily vegetated tropic environments.

6. BACKGROUND.

a. The performance of many modern weapons systems can be affected adversely by heavy concentrations of dust and smoke in the air. In recent years, a systematic effort has been underway to assess such effects, both in the field and through mathematical computer models, to meet the need for a more realistic battlefield representation. Basic computer models describing physical phenomena, such as scattering and absorption of radiation, have been applied to battlefield scenarios characterizing a wide range of conditions. The results have been used to produce parametric computer models for obscured conditions similar to certain geographic or climatic regions. In most cases, engineering computer models, developed to describe the performance of a number of weapons systems, have, or will have, incorporated such parametric models. While these models serve the needs of the engineering community in developing and, to some extent, evaluating such weapons systems, a further step is desired. That step is to use models to determine the effective deployment of weapons systems.

b. A fundamental gap must be bridged--the link betweeen obscurant material and terrain. Much of the obscurant material on the battlefield originates in the soil and is raised by battle activity. Before this link can be understood properly, the relationship between specific combat activities and obscurant production must be described accurately. This is the task of the USAWES/USATTC cooperative project. A FY80 methodology investigation, TECOM Project No. 7-CO-RDO-TT1-004, documented obscuration results of wet season detonations. The FY82 proposed investigation will document obscuration

results of dry season detonations, which are theorized to be markedly different.

7. GOAL. The aim of this investigation is to obtain information concerning the dust produced by explosives on different types of tropic soils with varying conditions.

8. DESCRIPTION.

a. The test will consist of detonations of a number of rounds of 155-millimeter and 105-millimeter ammunition, and of TNT in static configurations on or just beneath the soil surface; as well as six tube-delivered 105-millimeter rounds fired in both dry and wet season to provide correlation data between static above-ground detonations and tube-delivered rounds. Each detonation will be carefully logged and documented by photographic and physical methods to allow analysis of the growth and extent of the cloud, its correlation with meteorological conditions, and the effects of soil type, moisture, vegetation, etc. on its obscurant features. Specific measurements to be made and methods used are further described below.

b. Pretest survey and blast site location--Phase I.

(1) The target area is to be thoroughly tested to establish range and distribution of soil strength and moisture content over the area, and to locate inhomogeneities or pockets. Layered structure in cone index (CI) data should also be an object of the search. This is best done by initially setting a grid system of about 10-meter by 10-meter intervals over the target area. Intersection points are then marked by stakes and sampling done at those markers. Blast locations will be chosen for these points.

(2) Blast locations should be chosen to yield an adequate coverage of the range of conditions existing at the site and to allow meaningful comparison of results. That is, if moisture and CI both vary markedly the extremes would need to be tested, and an effort should be made to locate sites indicative of the four possible combinations (i.e., high MC-low CI, high MC-high CI, low MC-high CI and low MC-low CI). Similar guidelines will apply to other variables.

(3) At each combination of conditions a significant sampling is necessary. A minimum of four detonations at each is considered advisable here. Of course, if there are too many variables, some must be overlooked. For this purpose, a hierarchy is necessary in the importance of the soil variables.

Soil classification (visual).
Soil moisture.
Cone index (prefereably remoulding CI).
Plastic index.

This list gives the order of importance anticipated at present. Soil class here would be established visually. Variations in color, texture, consistency and structure are to be observed. Conditions that would produce wide lateral variations in the space occupied by a water should be avoided. Vertical variations should be carefully noted. Differences in texture and composition should also be carefully noted and if significant differences exist they should be covered in the tests.

(4) Soil moisture is next in importance and should be assessed at the surface and below the soil or A-horizon, but not deeper than the anticipated crater depth (about 1/2 meter for 155-millimeter and 3/10 meter for 105-millimeter rounds). CI has not so far proven very significant; however, it is believed that it should be third in importance. Plastic index is considered equally important, but since it is a laboratory test and not readily determined in the field, it is given lower significance. Any obvious variations in plasticity, however, should be considered in locating blast points.

(5) Bulk samples of 2 to 3 kilograms should be taken at each blast site for laboratory analysis. One is taken from the surface layer (usually 0-10 centimeter) before the blast at a point that will be beyond the crater rim. (If it is necessary to take the sample nearer the blast point, the resulting hole should be refilled with similar material to the original surface.) Another sample will be taken at the depth of the crater floor (see under post-test measurements). Bulk samples are to be sealed in plastic or sufficiently moisture-proof containers when they are taken and stored for transport to the laboratory.

c. Test phase data--Phase II.

(1) Observations during tests will consist of photographic coverage, sampling pans for collection of fallback material and samplers to collect cloud debris. This latter method is yet to be determined but may be pans, adhesive strips or filtered air-flow devices. The overall objective is to determine the mass of material in the cloud and in the initial fallback around the crater. The volume, growth and density of the cloud will be judged from the photography.

(2) The sampling pans for fallback are to be placed at successive distances from the blast center (point zero) of 1-1/2 R, 2R, 3R and 4R where R is the anticipated crater radius (1 meter for 155-millimeter and 0.75 meter for 105-millimeter rounds). Enough pans should be used to insure a representative sampling of distribution around the crater.

(3) Photography may be used in two ways. Simple documentation and cloud expansion data may be obtained with two cameras operated as a stereo pair or at right angles (the more preferable). Distances from and angles to point zero and to several reference points must be carefully recorded, and the lens parameters and fields of view are also necessary. For full camera coverage, stereo cameras are set up on opposing sides of the target area, and

a third pair is set at approximately a right angle to these for control. In all arrangements, it is necessary to operate all cameras simultaneously and voice communication between camera sites is highly desirable for this.

(4) The operations to be performed at the site following each shot are the recording of crater dimensions, CI at the rim and bottom of the crater, and sample collection. The crater depth and diameters at right angles are measured at the level of the original surface. Depth is taken from this level to the visible floor of the crater. CI should be taken just outside the rim beginning at the original surface. Any throw-out material should be scooped clear.

(5) Samples from the pans may be weighed at the site or bagged for later weighing. All samples from equal distances are added together. If air samplers are used, these will be analyzed by electronic microscopy and should be handled accordingly. There is no need to keep the individual samples separate unless they were taken at quite different times in the cloud history.

(6) Moisture content at the depth of each crater should also be determined. This is done by scooping out a section of wall to obtain a sample of original soil.

d. Laboratory analysis--Phase III.

(1) It is usually not practical to fully analyze each soil sample. Size gradations by sieve and hydrometer analysis should be made on a reasonable sampling of the site material. More surface samples than depth samples should receive this analysis. The samples chosen should provide a good representation of the area covered in testing. A total of ten samples with six from the surface would be a minimum.

(2) Plastic and liquid index and remoulded CI should be obtained from each crater site. Here again, the surface is regarded as more important than depth (in about the same ratio). Organic content should be measured for a representative sampling for sparsely vegetated sites. For soil, the sampling should also be representative and should include moisture counts.

e. Health Hazard Assessment. Participants will be within normal duty limits under conditions in which neither informed participation nor volunteer participation is required, i.e., no health hazards have been identified in this MIP. Similar activities in the past have not revealed any health hazards.

9. PROGRESS. FY80 investigation documented obscuration results of wet season detonations. FY82 dry season tests will complement previous investigation.

10. JUSTIFICATION.

a. This investigation will support ongoing work at US Army Engineer Waterways Experiment Station (USAWES) under DA Project No. 4A76270AT42 entitled "Improved Environmental Realism for Battlefield Simulation". This investigation conforms with the guidelines stated in Memorandum of Understanding (MOU) between the Office of the Chief of Engineers and the Commander, US Army Test and Evaluation Command regarding tropic environmental research.

b. Dollar Savings. The ultimate use of the results obtained in this investigation will be to develop more realistic models of the battlefield. Parametric models, for obscured conditions typical of heavily vegetated tropic environments, will undoubtedly lead to savings in cost of combat development experimentation. Estimation of savings cannot be approximated at this time.

c. Workload. As stated in 10a above, this is a cooperative project in Battlefield Obscuration.

d. Recommended TRMS Priority. Priority 1.

e. Association with Requirement Documents. Not applicable.

11. RESOURCES.

a. Financial.

(1) Funding breakdown:

Dollars (Thousands)

FY82

	In-House	Out-of-House
Personnel Compensation		
Travel	1.5	
Contractual Support		6.5
Consultants and Other Services		
Materials and Supplies	3.0	
Equipment	3.0	
Subtotal	7.5	6.5
FY Total	14.0	

(2) Explanation of Cost Categories:

(a) Personnel Compensation. Not applicable.

(b) Travel. Four trips to USATTC for initial detailed planning, on-site data gathering, and final reporting.

(c) Contractural Support. Support work at field sites and in the laboratories is accomplished by service contract personnel.

(d) Consultant and Other Services. Not applicable.

(e) Materials and Supplies. For use in detailed site measurements and lab soil analysis.

(f) Equipment. For minor soil and field aids.

b. Anticipated Delays. Requisitioning of 105-millimeter HE ammunition (27 rounds approximately) and 155-millimeter rounds (15 approximately) may be obtained locally. Support of the 193d Infantry Brigade (Panama) Artillery and Explosives Ordnance Detachment (EOD) units will have to be requested.

c. Obligation Plan.

FQ	2	3	4	TOTAL
Obligation Rate (Thousands)	5.0	6.0	3.0	14.0

d. In-House Personnel.

		FY 82 Man-Hours	
	No.	Required	Available
Test Off (MOS 75A00)	1	400	400
Engr Tech (GS0802)	1	400	400
Phys Science Admin (GS1301)	1	50	50
Math Stat (GS1529)	1	350	350
QA Specialist (GS1910)	1	100	100
ORSA (GS1515)	1	200	200
Photo-TV Spec (GS1060)	2	450	450
Support Personnel	5	480	480
		2,430	2,430

12. INVESTIGATION SCHEDULE.

	FY82								
	O	N	D	J	F	M	A	J	J
In-House	------------	------------	------------	------------	------------	------------	------------	------------	---R

Symbols: ----- Active investigation work
R Final Report at HQ TECOM

13. ASSOCIATION WITH TOP PROGRAM. Not applicable.

/s/Frank S. Mendez
/t/FRANK S. MENDEZ
C, Materiel Test Division

(END COPY)

APPENDIX B. PHOTOGRAPHIC DOCUMENTATION OF PROCEDURES

Figure B-1. Wooden Stand Holding Round at 30-degree Angle.

Figure B-2. TNT Configuration.

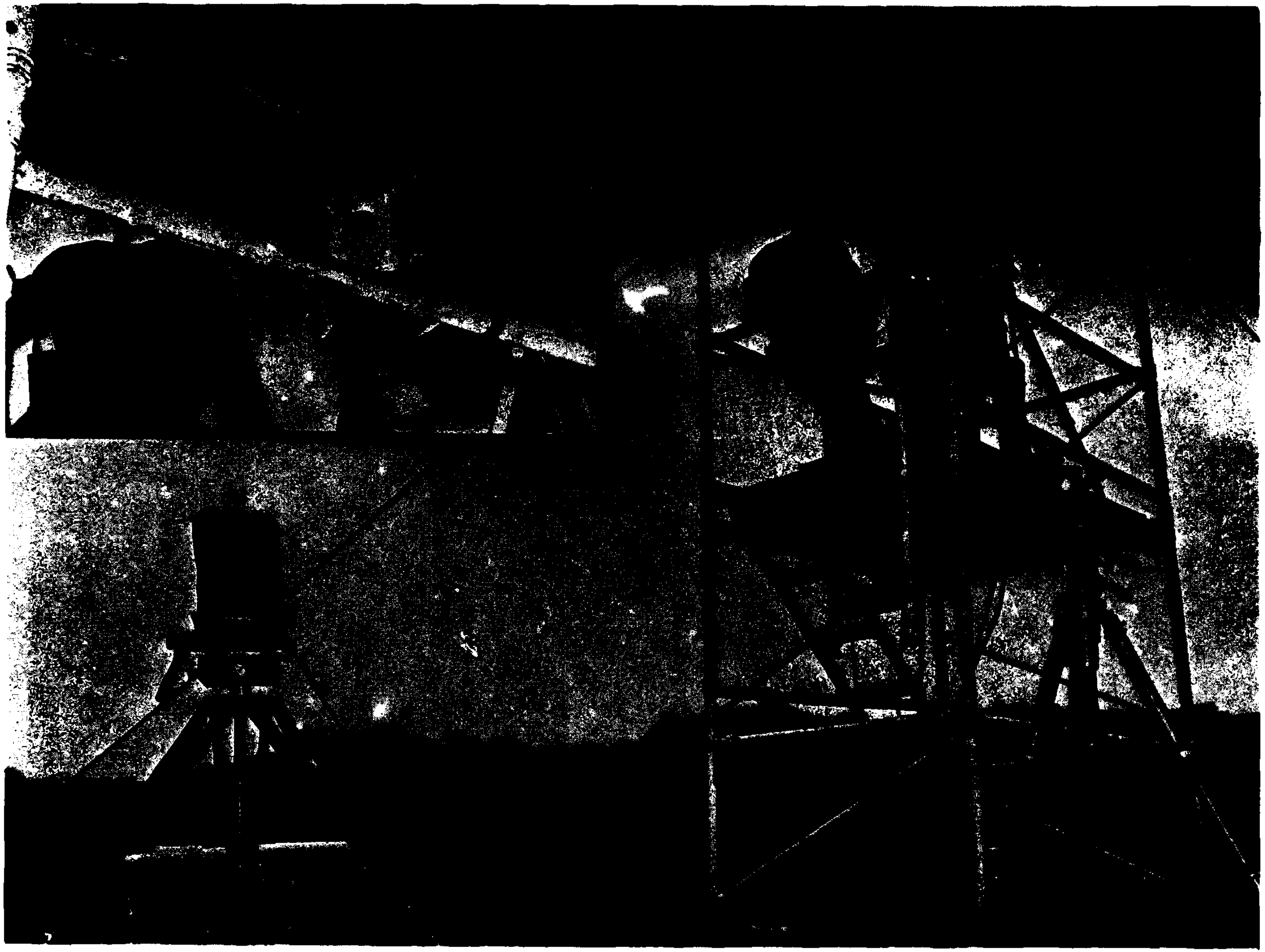


Figure B-3. Camera Position A at Empire Range 6.

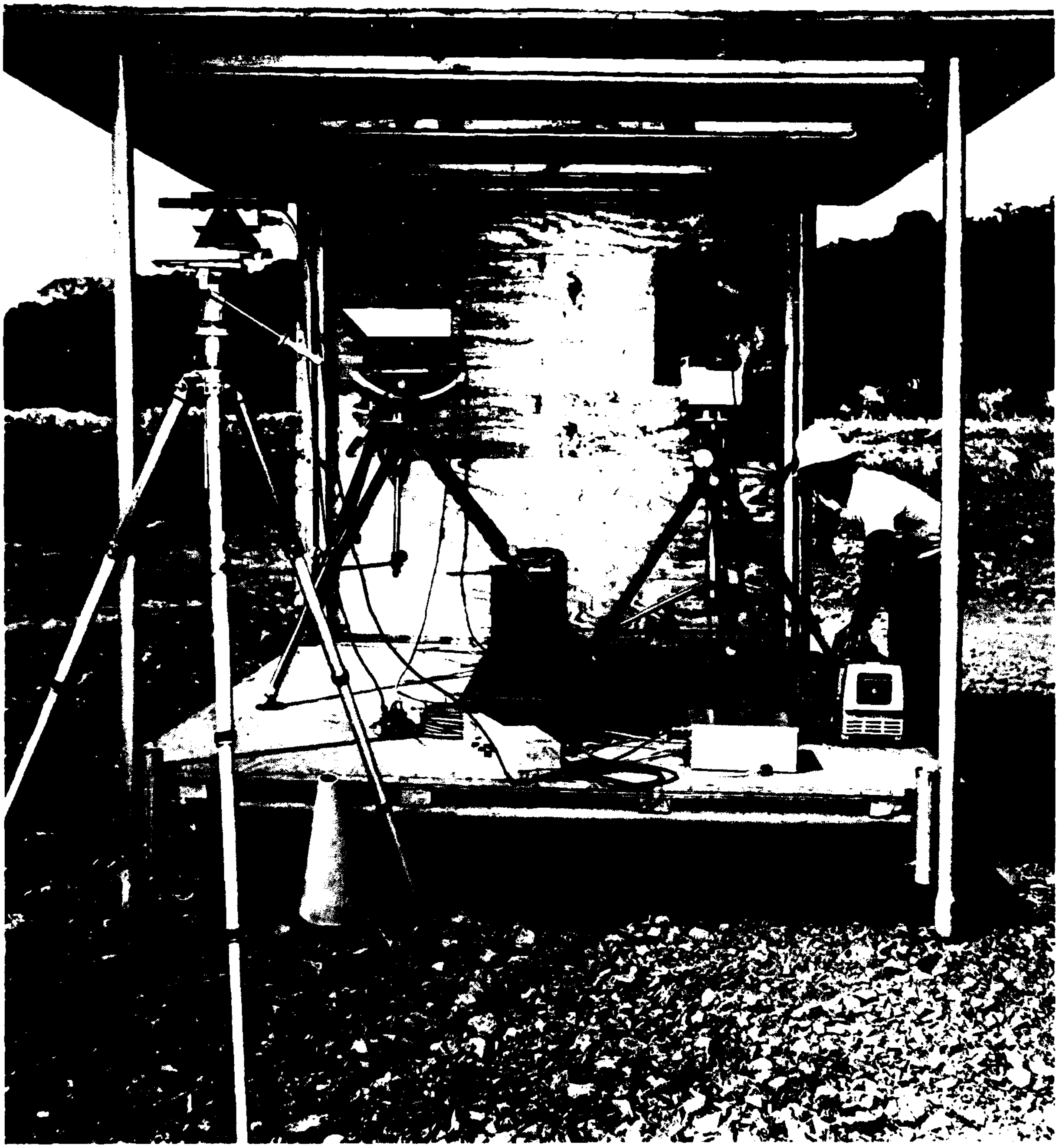


Figure B-4. Camera Position B at Empire Range 6.

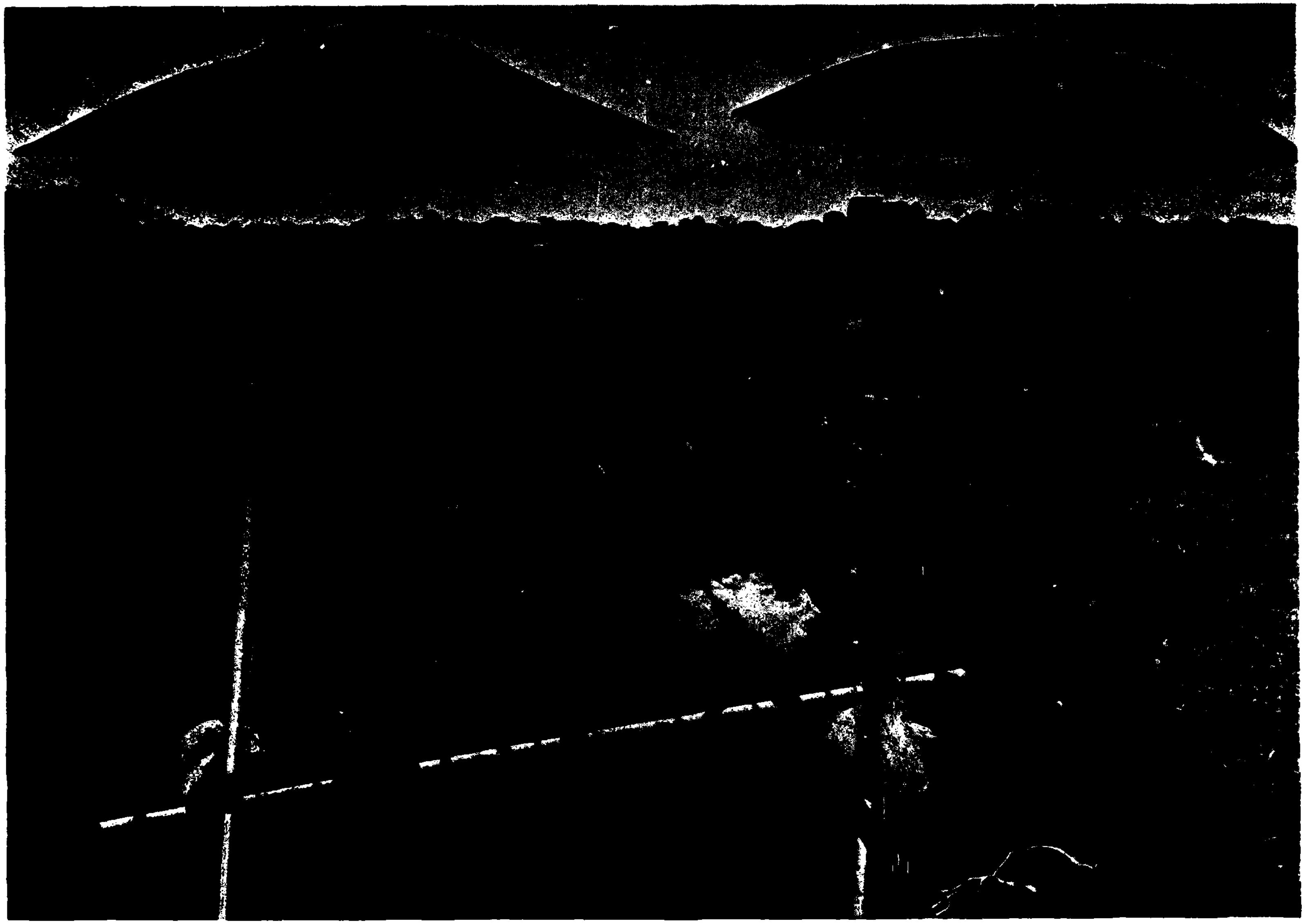


Figure B-5. Camera Configuration Used at Pina Beach and Mindi Farm.

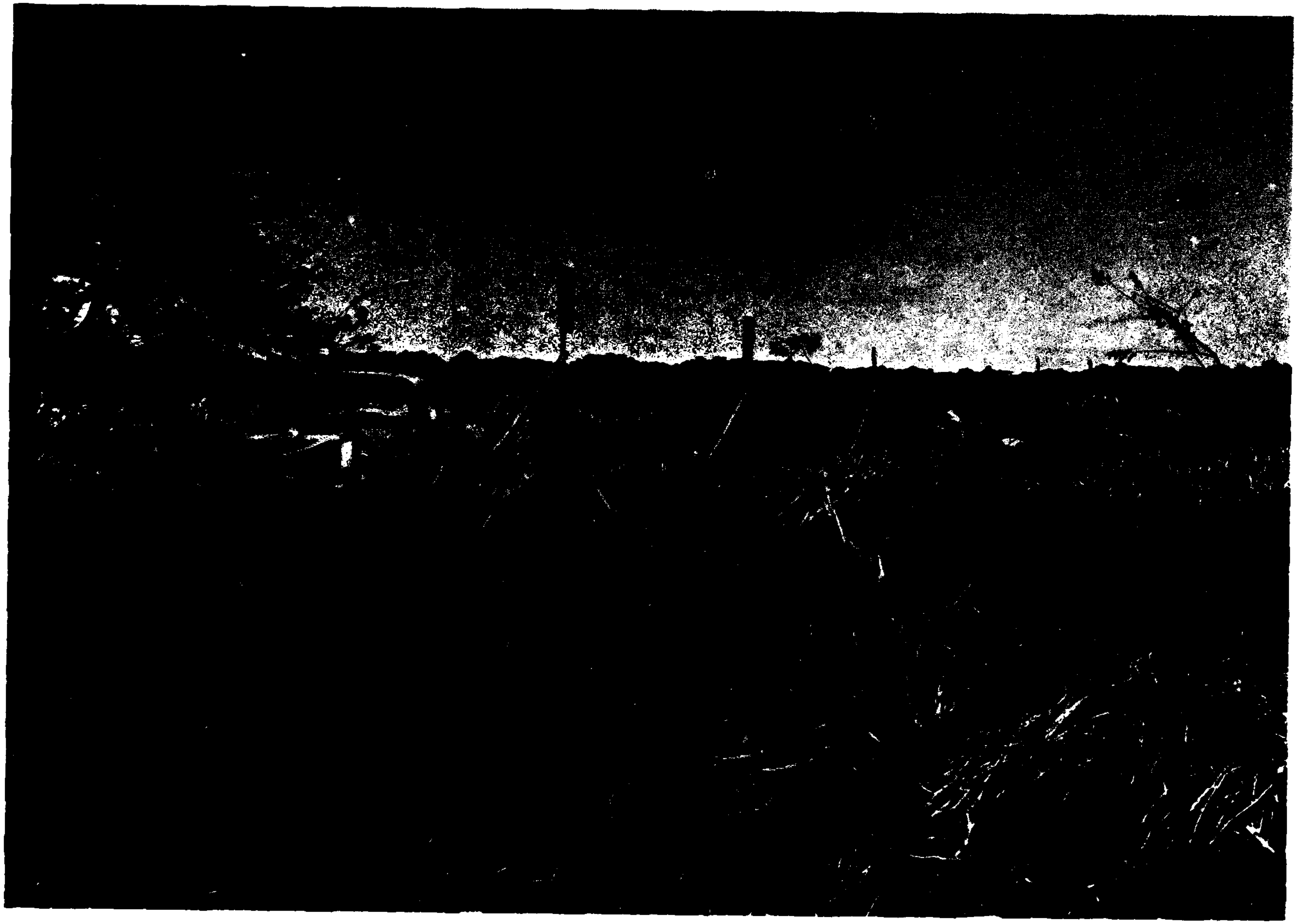


Figure B-6. Black and White Background Targets Used to Evaluate Cloud Opacity.

Figure B-7. Collecting Soils Data Using Cone Penetrometer.

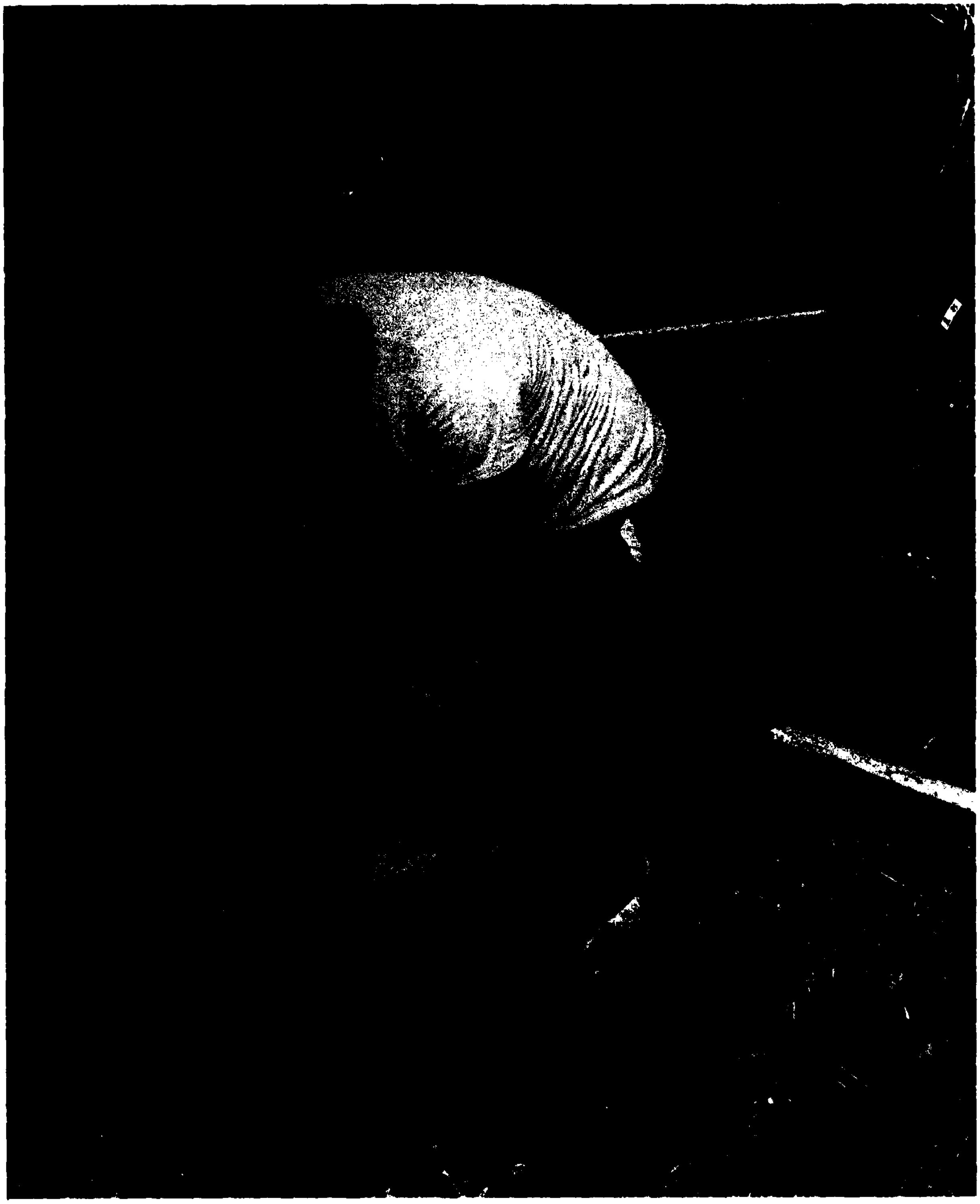


Figure B-8. Collecting Soil Sample Using Trafficability Sampler.

Figure B-9. Collecting Crater Blowout Material After Detonation.

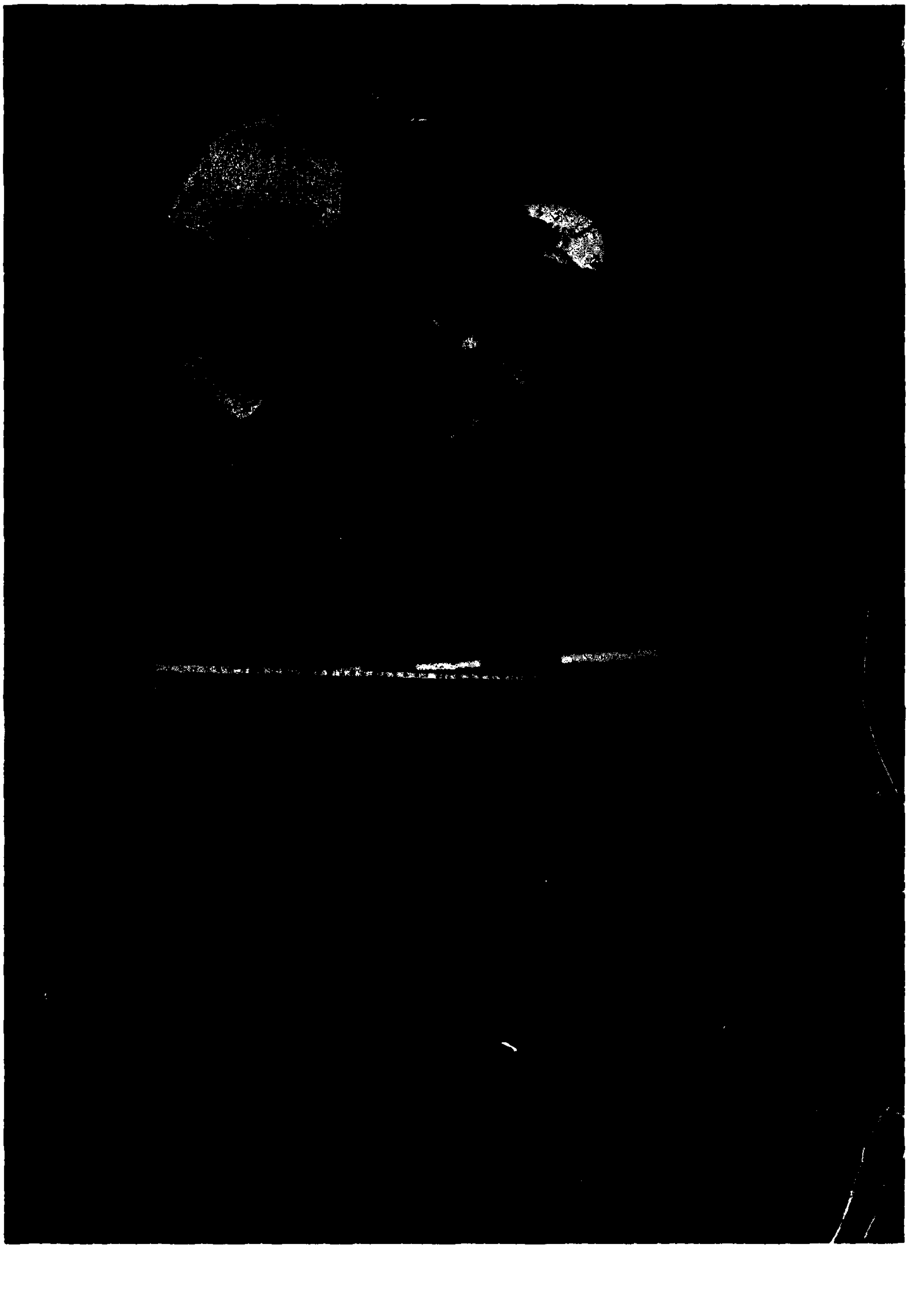


Figure B-10. Measuring Crater After Blast.

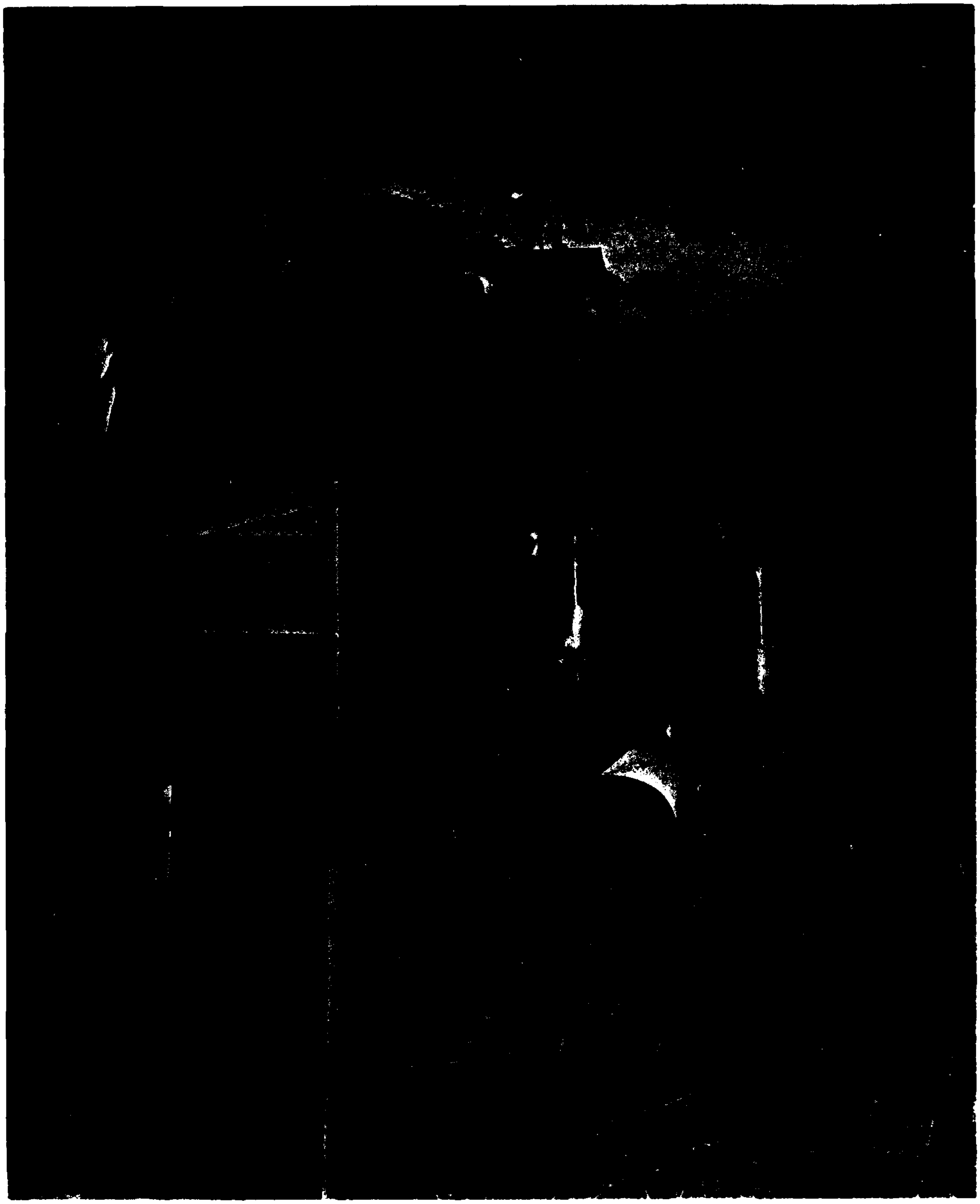


Figure B-11. Collecting Meteorological Data during Testing.

APPENDIX C. TABULATED TEST DATA

TABLE C-1. SITE DESCRIPTIONS, METEOROLOGICAL DATA, AND CRATER VOLUMES

CRATER	SITE	TIME	DATE	GRASS A/	VEGET B/	MUNITION	PRESSURE C/	TEMPERATURE TOWER 1M D/	TOWER 2M E/	TOWER 4M F/	GRASS 1M G/	GRASS 2M H/	REL HUM I/	PRECIP J/	WIND-SPEED 1M K/	2M L/	4M M/	AZIM N/	WIND DIRECTION 1M O/	2M P/	4M Q/	VOLUME WFB R/	VOLUME WnFo S/
1	MINDI	11:11	24FEB82	G	HG	155MM	1009	28.9	28.2	27.8	31.4	30.0	83	0.0	2	3	2	97	60	10	40	0.183	-
2	MINDI	11:54	24FEB82	G	HG	105MM	1009	28.3	27.4	27.7	31.4	29.3	73	0.0	6	8	6	95	20	360	360	0.193	0.283
3	MINDI	12:44	24FEB82	G	HG	TNT	1008	31.1	29.7	29.8	-	-	68	0.0	6	8	11	89	40	30	30	0.385	0.545
4	MINDI	13:14	23FEB82	G	CG	155MM	1008	31.1	29.4	28.9	-	-	66	0.0	8	10	11	93	45	30	30	0.537	0.600
5	MINDI	14:25	23FEB82	G	CG	105MM	1007	31.4	29.6	29.1	-	-	62	0.0	5	7	7	92	20	360	360	0.206	-
6	MINDI	10:10	23FEB82	G	CG	TNT	1009	26.6	26.1	25.8	31.4	30.2	77	0.0	2	3	3	92	30	350	60	0.228	-
7	MINDI	14:04	24FEB82	G	BS	155MM	1007	31.1	28.8	28.8	-	-	66	0.0	6	7	8	92	20	360	20	0.350	-
8	MINDI	15:02	24FEB82	G	BS	105MM	1006	30.5	29.8	28.4	-	-	71	0.0	4	8	10	91	10	10	20	0.172	-
9	MINDI	15:44	24FEB82	G	BS	TNT	1005	27.9	27.6	27.3	-	-	69	0.0	6	8	9	92	30	360	10	0.183	-
10	RANGE6	14:19	09MAR82	G	HG	155MM	999	32.4	32.1	32.8	37.8	36.2	38	0.0	8	8	10	289	NNW	N	N	0.242	-
11	RANGE6	15:08	09MAR82	G	HG	105MM	998	33.1	31.8	32.1	34.7	33.5	37	0.0	7	10	10	288	NNW	NNW	N	0.064	-
12	RANGE6	16:01	09MAR82	G	HG	TNT	997	30.6	30.0	30.5	31.7	30.1	47	0.0	6	8	9	290	NW	NNW	NNW	0.103	-
13	RANGE6	13:55	10MAR82	G	CG	155MM	997	32.4	30.9	30.5	-	-	48	0.0	7	9	9	288	NNW	NNW	N	0.277	0.323
14	RANGE6	14:48	10MAR82	G	CG	105MM	996	33.2	31.3	31.2	-	-	54	0.0	4	10	10	286	NNW	N	N	0.073	0.092
15	RANGE6	15:31	10MAR82	G	CG	TNT	996	32.3	32.3	32.2	-	-	52	0.0	8	12	11	286	NNW	N	N	0.099	-
16	RANGE6	09:53	11MAR82	G	BS	155MM	999	32.1	29.4	29.5	-	-	57	0.0	6	9	9	287	NNW	NNW	NNW	0.222	0.305
17	RANGE6	10:34	11MAR82	G	BS	105MM	999	30.7	29.5	31.0	-	-	50	0.0	6	8	8	287	NNW	NNW	NNW	0.156	-
18	RANGE6	11:25	11MAR82	G	BS	TNT	998	33.3	31.6	31.6	-	-	48	0.0	7	10	10	288	N	N	NNE	0.130	0.166
19	RANGE6	11:43	09MAR82	P	LG	155MM	1001	33.6	30.8	31.7	35.3	34.2	46	0.0	-	7	10	282	N	NNE	NNE	0.235	0.289
20	RANGE6	12:37	09MAR82	P	LG	105MM	1000	33.9	32.4	31.7	35.4	34.2	52	0.0	-	10	11	284	N	N	N	0.085	0.116
21	RANGE6	10:55	10MAR82	P	LG	TNT	999	30.6	29.2	28.9	34.4	31.4	71	0.0	8	10	11	284	NNW	N	N	0.075	-
22	RANGE6	11:44	10MAR82	P	CG	155MM	999	32.9	32.1	30.4	-	-	49	0.0	6	9	9	284	NNW	NNW	N	0.281	0.335
23	RANGE6	12:18	10MAR82	P	CG	105MM	998	30.2	29.5	29.6	-	-	52	0.0	7	11	11	282	NNW	N	N	0.094	0.131
24	RANGE6	13:02	10MAR82	P	CG	TNT	997	31.7	30.8	30.7	-	-	48	0.0	7	10	10	282	NW	NNW	N	0.151	0.247
25	RANGE6	12:16	11MAR82	P	BS	155MM	997	31.3	30.1	31.4	-	-	51	0.0	5	7	7	284	NNW	NNW	NNW	0.289	0.382
26	RANGE6	12:56	11MAR82	P	BS	105MM	997	32.4	32.1	32.2	-	-	47	0.0	7	10	9	284	NNW	NNW	N	0.114	-
27	RANGE6	13:33	09MAR82	P	BS	TNT	999	33.8	32.6	32.2	36.6	34.6	46	0.0	-	10	10	284	NNW	NNW	N	0.133	0.186
28	PINA	12:34	02MAR82	O	WS	TNT	1014	31.6	29.7	28.5	-	-	75	0.0	7	10	12	260	30	20	40	0.481	-
29	PINA	13:16	02MAR82	O	WS	TNT	1014	30.2	28.7	27.8	-	-	73	0.0	8	11	13	260	30	20	30	0.501	-
30	PINA	14:06	02MAR82	O	BL	TNT	1012	30.6	29.0	28.0	-	-	68	0.0	8	10	12	258	40	20	40	0.269	-
31	PINA	11:11	03MAR82	O	WS	TNT	1012	30.7	29.2	27.8	-	-	73	0.0	6	7	10	258	340	330	350	0.379	-
32	PINA	12:40	04MAR82	O	WS	TNT	1011	30.2	29.4	28.5	-	-	61	0.0	7	9	10	258	10	10	360	0.375	-
33	PINA	11:56	04MAR82	O	BL	TNT	1012	30.7	29.3	28.1	-	-	61	0.0	7	9	11	258	20	20	20	0.245	-
34	PINA	11:47	03MAR82	M	WS	TNT	1012	28.2	27.7	27.1	-	-	76	0.0	6	7	10	256	330	330	340	0.425	-

Table C-1 (cont)

CRATER	SITE	TIME	DATE	GRASS A/	VEGEST B/	MUNITION	PRESSURE C/	TEMPERATURE TOWER- 1M D/	2M E/	4M F/	GRASS 1M G/	2M H/	REL HUM I/	PRECIP J/	WIND-SPEED 1M K/	2M L/	4M M/	AZIMUN N/	WIND DIRECTION 1M O/	2M P/	4M Q/	VOLUME WFB R/	WCFBS S/
35	PINA	12:34	03MAR82	M	WS	TNT	1012	29.5	27.9	27.6	-	-	79	0.8	6	10	13	256	350	340	330	0.227	-
36	PINA	13:10	03MAR82	S	WS	TNT	1011	29.4	27.9	27.8	-	-	70	0.0	8	12	15	254	360	360	360	0.186	-
37	PINA	13:46	03MAR82	S	WS	TNT	1011	29.9	28.4	28.1	-	-	71	0.0	8	12	15	254	10	350	360	0.163	-
38	PINA	10:54	04MAR82	P	HG	TNT	1013	29.9	28.8	28.3	32.8	31.0	65	0.0	7	10	11	254	20	20	360	0.284	-
39	PINA	11:24	04MAR82	P	HG	TNT	1012	30.6	28.6	27.9	32.1	31.8	63	0.0	8	10	11	252	20	10	10	0.244	-
40	RCLAY_R6	-	12MAR82	-	-	155MM	-	-	-	-	-	-	-	-	-	-	-	284	-	-	-	-	-
41	RCLAY_R5	-	12MAR82	-	-	TNT	-	-	-	-	-	-	-	-	-	-	-	284	-	-	-	-	-
42	R10_D	-	12MAR82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.296	-
43	R10_D	-	12MAR82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.132	-
44	R10_D	-	12MAR82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.178	-
45	R10_D	-	12MAR82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.137	-
46	R10_D	-	12MAR82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.329	-
47	R10_D	-	12MAR82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.128	-
48	R10_W	-	14JUL82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.415	-
49	R10_W	-	14JUL82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.452	-
50	R10_W	-	14JUL82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.415	-
51	R10_W	-	14JUL82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.326	-
52	R10_W	-	14JUL82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.235	-
53	R10_W	-	14JUL82	-	-	IF105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.372	-

Table C-1 (concluded)

a/ Grass Type
G = *Gynerium sagittatum*
P = *Panicum* sp (1-2 m tall)
O = Other
M = Morning Glory
S = Spider Lily

b/ Vegetation
HG = High Grass
CG = Cut Grass
BS = Bare Soil
LG = Low Grass
WS = Wet Sand
BL = Black Sand

c/ Barometric Pressure (millibars)

d/ Temperature (°C) out of grass at 1 meter above ground level

e/ Temperature (°C) out of grass at 2 meters above ground level

f/ Temperature (°C) out of grass at 4 meters above ground level

g/ Temperature (°C) in grass at 1 meter above ground level

h/ Temperature (°C) in grass at 2 meters above ground level

i/ Relative Humidity (%)

j/ Precipitation (cm)

k/ Windspeed (knots) at 1 meter above ground level

l/ Windspeed (knots) at 2 meters above ground level

m/ Windspeed (knots) at 4 meters above ground level

n/ Azimuth (degrees) of line of site from observation point to blast site

o/ Wind Direction (degrees) at 1 meter above ground level

p/ Wind Direction (degrees) at 2 meters above ground level

q/ Wind Direction (degrees) at 4 meters above ground level

r/ Crater Volume (m^3) with fallback

s/ Crater Volume (m^3) without fallback

TABLE C-2. CLOUD GROWTH DATA

CRATER	OBSCURED AREA SECONDS AFTER DETONATION (M2) 1	2	10	20	40	CLOUD CENTER COORDINATES [BLAST SITE = 0.0] (M) X 1	X 2	X 5	X 10	X 20	Y 1	Y 2	Y 5	Y 10	Y 20
1	175	199	128	23	0	2.8	4.0	3.2	-3.6	-	4.9	4.2	4.2	5.9	-
2	63	83	0	0	0	-0.8	-5.5	-12	-	-	4.2	3.1	1.7	-	-
3	79	165	0	0	0	-1.5	-4.6	-12	-	-	4.1	4.8	7.2	-	-
4	101	145	0	0	0	0.0	-7.3	-14	-	-	6.6	8.0	3.1	-	-
5	51	17	0	0	0	-2.5	-3.4	-1.3	-	-	2.8	1.8	1.4	-	-
6	124	160	251	233	0	0.4	0.0	-4.1	-11	-0.2	3.7	4.4	7.5	9.8	1.7
7	123	156	0	0	0	-5.8	-9.3	-22	-	-	5.3	6.0	7.0	-	-
8	67	62	0	0	0	-1.6	-2.0	-	-	-	3.9	3.6	-	-	-
9	96	165	0	0	0	-3.0	-8.5	-25	-	-	4.5	4.9	6.2	-	-
10	103	199	238	403	0	-2.7	-1.8	-1.5	10.4	-	4.0	5.1	6.1	7.1	-
11	67	118	254	116	0	0.9	2.8	8.8	16.6	-	2.4	3.9	8.3	8.8	-
12	134	151	535	1045	0	3.5	14.8	18.8	15.9	-	4.9	7.4	3.0	21.2	-
13	177	242	398	725	0	0.7	4.0	-	-	-	3.8	3.8	-	-	-
14	221	297	411	92	0	0.0	7.0	-1.8	-	-	7.0	9.6	11.5	-	-
15	431	565	1711	2250	0	0.0	-2.6	4.9	-	-	7.2	2.0	13.1	-	-
16	155	227	814	1283	0	1.1	4.0	0.4	-0.7	-	4.4	6.3	6.9	8.2	-
17	89	125	770	419	0	0.7	1.4	1.1	1.1	2.8	1.8	4.3	4.9	8.6	3.7
18	105	180	678	459	0	0.7	2.8	0.4	24.9	-	3.1	5.0	10.5	21.7	-
19	131	256	426	467	0	5.4	3.4	-	1.7	-	4.3	4.8	-	0.5	-
20	80	64	0	0	0	0.6	-0.9	-	-	-	1.5	2.4	-	-	-
21	228	436	0	0	0	5.6	9.3	18.9	-	-	6.7	10.6	19.2	-	-
22	152	222	458	767	0	5.6	7.1	-	-	-	3.3	3.9	-	-	-
23	77	189	360	0	0	0.4	7.8	16.0	0.4	-	2.6	1.9	3.9	7.1	-
24	180	339	993	0	0	0.3	2.1	14.6	-	-	5.2	6.7	15.0	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	90	139	252	0	0	3.5	1.7	2.4	29.7	-	4.3	3.6	9.1	23.1	-
27	84	179	642	678	0	0.0	5.8	17.2	45.4	-	4.0	7.0	12.9	25.8	-
28	98	160	226	0	0	5.6	10.2	-	-	-	4.9	6.6	-	-	-
29	121	159	0	0	0	5.1	11.7	27.5	-	-	6.0	8.4	15.0	-	-
30	96	114	183	0	0	4.6	8.4	0.0	-	-	4.1	5.5	0.3	-	-

Table C-2 (concluded)

CRATER	OBSCURED AREA SECONDS AFTER DETONATION (M2) 1	2	10	20	40	CLOUD CENTER COORDINATES [BLAST SITE = 0,0] (M) X1	X2	X5	X10	X20	Y1	Y2	Y5	Y10	Y20
31	104	146	262	0	0	2.0	5.7	21.3	–	–	.9	6.8	13.9	–	–
32	92	132	214	0	0	6.0	8.9	21.8	–	–	4.1	3.5	10.9	–	–
33	88	121	0	0	0	7.6	12.1	27.6	–	–	4.4	6.9	14.1	–	–
34	107	153	453	0	0	7.2	10.3	-22	–	–	3.6	5.0	0.3	–	–
35	87	125	221	238	0	5.1	10.3	13.2	-4.2	–	1.1	3.6	12.1	2.8	–
36	76	118	225	0	0	6.6	12.0	–	20.7	–	3.6	4.4	–	10.8	–
37	93	114	252	0	0	6.7	12.4	–	–	–	4.8	1.3	–	–	–
38	90	90	128	0	0	3.2	6.4	-2.5	16.9	–	2.1	2.8	0.3	0.0	–
39	70	99	357	342	0	1.9	3.4	3.4	21.3	–	2.0	2.3	0.3	0.0	–
40	129	168	683	1905	0	-0.6	-0.6	6.8	15.7	12.8	3.1	3.1	5.1	7.2	16.4
41	75	152	558	1163	0	0.0	0.3	2.4	6.8	27.4	1.5	2.0	7.7	12.3	29.8

NOTES: 1. FOR THOSE AREAS WITH DASHES, DATA COULD NOT BE COMPUTED FROM VIDEO TAPE.
2. CLOUD GROWTH DATA WERE NOT COLLECTED FOR TUBE-DELIVERED ROUNDS (42 - 53).

TABLE C-3. SOILS ANALYSIS DATA

AVERAGE CONE INDEX AT DEPTHS INDICATED A/

		GROUND SURFACE BEFORE DETONATION (KG/CM2)									CRATER RIM (KG/CM2)								
CRATER	DEPTH	0 IN	2 IN	4 IN	6 IN	9 IN	12 IN	15 IN	18 IN	24 IN	0 IN	2 IN	4 IN	6 IN	9 IN	12 IN	15 IN	18 IN	24 IN
1	0.22	4.4	9.5	27.1	33.7	47.8	47.8	48.5	49.2	50.3	2.8	14.8	23.2	34.4	36.5	48.5	48.5	52.0	52.7
2	0.19	3.7	9.8	15.6	25.3	30.2	39.7	49.2	52.7	52.7	6.0	18.6	29.5	34.4	38.7	40.1	48.5	52.7	52.7
3	0.55	3.5	8.4	12.8	18.6	20.4	27.4	36.9	36.5	42.5	4.2	10.2	11.9	17.6	22.8	28.8	33.0	35.1	33.0
4	0.31	6.3	11.1	17.0	19.3	24.6	24.8	21.4	23.2	37.2	3.3	9.5	13.5	17.6	19.2	21.1	25.7	31.3	41.5
5	0.29	7.4	12.7	15.8	21.1	21.8	25.7	30.2	36.2	40.1	4.7	11.1	16.7	20.6	23.2	26.4	34.4	42.2	47.9
6	0.37	5.6	11.4	13.2	16.3	21.1	28.8	30.9	33.0	40.1	3.9	8.1	12.8	16.5	19.3	28.5	23.9	36.5	30.9
7	0.30	5.3	11.2	13.5	16.5	19.7	27.4	30.2	26.0	32.3	4.9	13.0	15.1	15.5	21.4	20.4	23.9	33.0	26.4
8	0.26	7.9	14.8	17.9	19.7	28.8	41.5	45.7	47.4	48.5	5.4	15.5	19.7	22.5	24.6	33.7	45.0	47.8	49.5
9	0.32	5.6	13.0	17.2	21.1	29.5	33.7	33.7	42.2	47.8	6.3	11.6	14.4	19.7	22.5	21.8	23.5	30.9	40.1
10	0.32	18.6	40.4	50.6	52.7	52.7	52.7	52.7	52.7	52.7	14.4	39.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7
11	0.16	15.6	51.0	52.7	52.7	52.7	52.7	52.7	52.7	52.7	19.2	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7
12	0.28	16.9	48.8	52.7	52.7	52.7	52.7	52.7	52.7	52.7	11.2	32.3	51.0	52.7	52.7	52.7	52.7	52.7	52.7
13	0.25	16.2	34.8	52.0	52.7	52.7	52.7	52.7	52.7	52.7	14.9	44.6	52.7	52.7	52.7	52.7	52.7	52.7	52.7
14	0.12	15.1	40.6	52.7	52.7	52.7	52.7	52.7	52.7	52.7	14.1	45.9	52.7	52.7	52.7	52.7	52.7	52.7	52.7
15	0.24	16.0	43.9	52.7	52.7	52.7	52.7	52.7	52.7	52.7	13.5	36.4	52.7	52.7	52.7	52.7	52.7	52.7	52.7
16	0.24	15.6	26.4	52.7	52.7	52.7	52.7	52.7	52.7	52.7	13.7	46.4	52.7	52.7	52.7	52.7	52.7	52.7	52.7
17	0.11	11.4	26.0	52.7	52.7	52.7	52.7	52.7	52.7	52.7	22.3	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7
18	0.23	17.2	34.4	52.7	52.7	52.7	52.7	52.7	52.7	52.7	16.0	29.8	49.2	52.7	52.7	52.7	52.7	52.7	52.7
19	0.16	17.9	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	19.0	43.4	52.7	52.7	52.7	52.7	52.7	52.7	52.7
20	0.17	17.4	43.2	52.7	52.7	52.7	52.7	52.7	52.7	52.7	18.1	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7
21	0.22	15.1	39.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	14.2	36.5	52.7	52.7	52.7	52.7	52.7	52.7	52.7
22	0.22	24.4	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	20.6	44.3	52.7	52.7	52.7	52.7	52.7	52.7	52.7
23	0.18	14.1	38.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	13.4	38.0	52.7	52.7	52.7	52.7	52.7	52.7	52.7
24	0.30	14.6	36.5	52.7	52.7	52.7	52.7	52.7	52.7	52.7	16.5	41.8	52.7	52.7	52.7	52.7	52.7	52.7	52.7
25	0.23	18.4	41.8	52.7	52.7	52.7	52.7	52.7	52.7	52.7	18.4	48.5	52.7	52.7	52.7	52.7	52.7	52.7	52.7
26	0.14	19.0	38.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	15.5	34.3	52.7	52.7	52.7	52.7	52.7	52.7	52.7
27	0.25	14.4	45.3	52.7	52.7	52.7	52.7	52.7	52.7	52.7	14.6	27.8	46.4	52.7	52.7	52.7	52.7	52.7	52.7
28	0.36	0.9	1.6	2.5	3.9	4.6	6.7	9.8	12.8	15.1	0.0	1.2	3.5	3.3	3.7	4.4	6.9	8.1	10.5
29	0.39	0.9	1.9	2.5	3.5	4.0	4.7	4.2	7.9	11.2	0.0	0.9	1.6	1.8	2.6	3.0	3.5	4.9	12.8
30	0.27	0.9	4.4	4.4	7.0	5.1	7.9	18.6	25.7	24.9	0.5	2.1	3.2	3.5	3.7	4.9	7.5	12.8	16.2
31	0.32	0.2	3.3	7.2	8.6	9.3	14.1	22.8	33.4	48.5	0.2	0.7	2.3	3.0	3.7	6.3	14.4	23.2	35.8
32	0.38	0.0	1.6	3.9	4.4	7.4	8.1	6.9	9.8	10.5	0.0	1.2	2.3	2.8	3.7	3.7	4.2	6.9	9.8
33	0.30	0.0	4.6	7.6	10.0	10.2	10.9	18.3	25.3	31.3	0.0	1.8	3.3	3.9	4.4	4.6	6.5	8.3	13.0
34	0.38	0.0	1.9	4.4	7.4	6.5	5.6	6.5	7.9	14.8	0.0	0.9	3.7	4.4	4.7	4.0	6.0	6.0	13.5
35	0.29	0.0	2.5	4.9	6.0	5.4	7.7	11.1	11.4	40.8	0.0	0.7	1.9	3.3	4.7	5.8	7.9	11.4	26.4
36	0.24	0.7	2.6	4.7	6.9	30.2	52.7	52.7	52.7	52.7	0.0	1.4	2.1	4.0	13.9	27.8	40.1	39.0	39.0
37	0.14	0.0	2.8	4.0	8.8	39.4	52.7	52.7	52.7	52.7	0.0	0.7	2.3	8.8	41.8	52.7	52.7	52.7	52.7
38	0.37	2.1	12.7	28.1	45.0	52.7	52.7	52.7	52.7	52.7	1.1	6.9	9.1	24.2	43.4	52.7	52.7	52.7	52.7
39	0.39	5.3	13.4	18.4	26.4	43.9	50.1	51.0	52.7	52.7	1.8	9.2	12.7	16.3	29.9	39.5	44.8	52.7	52.7

40 - 53 DATA NOT COLLECTED FOR RED CLAY AND TUBE-DELIVERED ROUNDS.

Table C-3 (cont)

CRATER	AVERAGE CONE INDEX AT DEPTHS INDICATED A/ BOTTOM OF CRATER (KG/CM2) 0 IN	2 IN	4 IN	6 IN	9 IN	12 IN	15 IN	18 IN	24 IN	MOISTURE CONTENT B/ SURFACE	BOTTOM	DENSITY (KG/M3) C/ WET	DRY
1	2.3	8.6	22.5	42.5	48.5	52.7	52.7	52.7	52.7	43.6	38.6	1301	907
2	6.3	16.9	34.4	47.1	52.7	52.7	52.7	52.7	52.7	51.5	41.8	1227	811
3	4.2	8.8	11.4	11.9	12.3	12.3	11.8	15.1	17.6	66.6	49.9	1402	841
4	3.9	10.5	14.2	11.2	14.4	12.1	18.4	33.7	45.0	65.1	55.7	1475	894
5	6.9	12.5	15.6	17.2	24.6	35.8	40.1	48.5	52.7	59.8	52.5	1418	887
6	1.6	4.4	7.2	8.1	10.7	16.9	25.3	33.0	42.9	78.1	53.4	1398	785
7	4.4	7.0	9.5	12.3	12.3	14.1	15.5	27.4	39.4	62.8	52.4	1357	833
8	6.0	13.0	15.3	14.8	26.7	33.4	40.8	45.0	46.4	51.9	51.2	1317	867
9	3.2	4.9	9.5	9.8	13.4	20.0	32.3	45.0	52.7	60.4	49.7	1426	889
10	7.4	17.9	28.8	26.4	30.2	30.9	38.7	41.8	52.7	22.6	26.1	995	811
11	4.2	22.1	49.5	52.7	52.7	52.7	52.7	52.7	52.7	17.4	22.6	1291	1100
12	9.5	43.4	52.7	52.7	52.7	52.7	52.7	52.7	52.7	18.7	24.2	1140	959
13	6.3	19.2	52.7	52.7	52.7	52.7	52.7	52.7	52.7	11.5	18.4	1124	1009
14	16.0	43.0	52.7	52.7	52.7	52.7	52.7	52.7	52.7	13.5	20.2	1019	899
15	9.1	16.5	22.1	27.8	30.2	34.4	38.3	44.3	51.8	11.1	21.8	1177	1060
16	14.1	31.6	52.7	52.7	52.7	52.7	52.7	52.7	52.7	12.8	15.5	1398	1240
17	13.4	23.2	47.1	52.7	52.7	52.7	52.7	52.7	52.7	12.4	17.5	1538	1370
18	11.9	37.6	52.7	52.7	52.7	52.7	52.7	52.7	52.7	13.3	18.2	1450	1280
19	21.1	46.4	52.7	52.7	52.7	52.7	52.7	52.7	52.7	15.7	23.1	1334	1153
20	11.6	27.8	49.2	52.7	52.7	52.7	52.7	52.7	52.7	17.6	19.9	1209	1028
21	10.9	32.0	52.7	52.7	52.7	52.7	52.7	52.7	52.7	12.5	18.9	1264	1124
22	14.6	41.1	52.7	52.7	52.7	52.7	52.7	52.7	52.7	18.3	18.6	1184	1001
23	17.9	52.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	17.0	19.4	1233	1059
24	12.1	35.1	48.5	52.7	52.7	52.7	52.7	52.7	52.7	13.1	22.1	1245	1100
25	13.0	23.9	38.7	50.3	52.7	52.7	52.7	52.7	52.7	20.4	16.5	1160	963
26	11.1	27.8	42.2	52.7	52.7	52.7	52.7	52.7	52.7	18.1	18.5	1267	1073
27	16.3	38.7	52.7	52.7	52.7	52.7	52.7	52.7	52.7	15.1	20.1	1275	1107
28	1.8	4.6	5.8	5.6	7.2	13.0	18.3	19.9	23.2	5.4	8.0	1378	1307
29	1.2	2.5	3.3	5.3	10.2	13.9	20.4	22.0	39.4	5.9	8.2	1410	1329
30	1.1	4.2	5.6	7.4	9.7	10.2	13.4	14.6	19.3	6.6	8.5	2214	2076
31	1.4	8.6	12.3	16.5	19.2	19.9	18.6	20.2	22.1	4.5	5.5	1501	1435
32	0.0	2.5	4.2	4.4	5.4	6.1	7.4	9.7	12.7	3.0	4.9	1523	1478
33	1.4	5.1	6.3	7.0	9.0	9.0	12.5	15.1	29.5	5.1	7.9	2026	1929
34	0.0	3.7	5.6	7.4	11.4	11.9	14.8	17.0	22.8	3.6	6.6	1658	1599
35	0.4	3.9	7.4	9.1	11.9	16.5	19.7	23.5	25.7	5.7	3.1	1930	1826
36	0.2	5.6	17.4	20.7	22.5	22.5	23.9	24.4	35.1	7.0	12.8	1675	1567
37	0.2	2.3	21.1	32.7	39.4	46.0	42.2	40.8	43.2	11.8	3.0	1589	1422
38	2.1	27.1	31.6	35.8	39.4	38.3	36.2	35.1	44.3	13.3	8.6	1248	1102
39	2.8	15.8	30.6	44.5	47.1	47.1	46.0	44.1	45.5	16.5	12.5	1410	1211
40	-	-	-	-	-	-	-	-	-	13.0	13.0	-	-
41	-	-	-	-	-	-	-	-	-	9.2	9.2	-	-

Table C-3 (cont)

CRATER	AVERAGE CONE INDEX AT DEPTHS INDICATED a/ BOTTOM OF CRATER (KG/CM2)									MOISTURE CONTENT b/		DENSITY (KG/M3) c/	
	0 IN	2 IN	4 IN	6 IN	9 IN	12 IN	15 IN	18 IN	24 IN	SURFACE	BOTTOM	WET	DRY
42	-	-	-	-	-	-	-	-	-	17.7	32.7	1280	1088
43	-	-	-	-	-	-	-	-	-	17.5	31.6	993	846
44	-	-	-	-	-	-	-	-	-	16.0	33.8	1094	948
45	-	-	-	-	-	-	-	-	-	25.1	34.0	1131	903
46	-	-	-	-	-	-	-	-	-	25.3	29.9	1145	913
47	-	-	-	-	-	-	-	-	-	32.2	36.1	1390	1051
48	-	-	-	-	-	-	-	-	-	56.1	46.3	1304	836
49	-	-	-	-	-	-	-	-	-	67.0	50.6	1272	761
50	-	-	-	-	-	-	-	-	-	50.6	53.8	1446	967
51	-	-	-	-	-	-	-	-	-	48.4	45.6	1643	1107
52	-	-	-	-	-	-	-	-	-	50.4	38.4	1442	958
53	-	-	-	-	-	-	-	-	-	45.9	23.4	1626	1115

a/ Mean CI values are an average of all CI readings taken at each crater site. Readings were taken at 0-, 2-, 4-, 6-, 9-, 12-, 15-, 18-, and 24-inch depths.

b/ Moisture content (% of dry weight) at crater surface and crater bottom.

c/ Density at 0-3 inches.

TABLE C-4. SOIL DESCRIPTION

		Mechanical Analysis (%)				Unified Soil Class Sys (%)							Mechanical Analysis (%)				Unified Soil Class Sys (%)					
									Atterburg Limits (%) b/											Atterburg Limits (%) b/		
Crater	Layer (In)	Gravel	Sand	Silt	Clay	Class a/	Fines	Org Mat	LL	PL	PI	Layer (In)	Gravel	Sand	Silt	Clay	Class a/	Fines	Org Mat	LL	PL	PI
1	0-6	0	35	55	10	MH	65	1.95	63	52	11	06-12	2	28	64	6	MH	70	2.69	58	44	14
2	0-6	1	44	53	2	MH	55	2.50	53	40	13	06-12	3	37	55	5	MH	60	0.95	61	40	21
3	0-6	0	34	51	15	MH	66	5.61	55	40	15	18-24	0	38	52	10	MH	62	2.30	59	46	13
4	0-6	3	22	40	35	MH	75	3.05	83	52	31	12-18	1	34	45	20	MH	65	4.70	61	31	30
5	0-6	0	38	57	5	MH	62	3.50	64	47	17	06-12	2	39	52	7	MH	59	1.65	66	41	25
6	0-6	0	43	51	6	MH	57	0.95	61	50	11	12-18	0	31	59	10	MH	69	0.20	51	39	12
7	0-6	1	35	61	3	MH	57	0.53	55	46	9	06-12	3	26	64	7	MH	71	0.12	71	44	27
8	0-6	2	26	70	2	MH	72	0.42	58	44	14	06-12	0	33	55	12	MH	67	0.21	52	45	7
9	0-6	0	30	45	25	MH	70	3.07	84	53	31	12-18	0	35	45	20	MH	65	2.60	57	43	14
10	0-6	7	23	55	15	MH	70	1.97	56	40	16	12-18	3	25	53	19	MH	72	0.68	55	41	14
11	0-6	10	25	45	20	MH	65	2.81	59	48	11	06-12	11	13	14	62	CL	76	2.63	47	22	25
12	0-6	6	22	57	15	MH	72	1.97	57	40	17	06-12	12	21	49	18	MH	67	0.73	55	35	20
13	0-6	11	23	41	25	OH	66	12.09	60	31	29	06-12	9	19	52	20	MH	72	4.61	58	40	18
14	0-6	10	35	49	6	MH	55	1.71	56	40	16	06-12	15	14	56	15	ML	71	1.03	48	34	14
15	0-6	3	27	54	16	MH	70	0.79	61	41	20	06-12	7	32	48	13	MH	61	1.03	54	41	13
16	0-6	5	20	55	20	ML	75	1.03	49	35	14	06-12	9	21	50	20	ML	70	1.60	45	33	12
17	0-6	2	30	54	14	MH	68	4.09	58	36	22	06-12	6	32	47	15	MH	62	2.06	57	36	21
18	0-6	4	36	51	9	MH	60	1.69	55	38	17	06-12	10	32	54	4	MH	58	1.02	50	34	16
19	0-6	2	23	15	60	CL	75	1.31	49	23	26	06-12	2	30	30	38	CL	68	0.97	44	21	23
20	0-6	3	37	47	13	MH	60	0.69	50	40	10	06-12	5	30	50	15	MH	65	0.09	58	43	15
21	0-6	13	30	51	6	MH	57	3.07	54	34	20	06-12	16	14	50	20	MH	70	1.09	60	40	20
22	0-6	9	23	38	30	OH	68	12.20	61	39	22	06-12	4	30	23	43	ML	66	1.50	45	28	17
23	0-6	6	16	8	70	CH	78	3.60	68	24	44	06-12	2	28	45	25	MH	70	2.05	66	39	27
24	0-6	5	27	53	15	ML	68	4.45	47	37	10	12-18	10	25	45	20	MH	65	2.60	55	41	14
25	0-6	4	27	54	15	ML	69	4.60	43	33	10	06-12	3	23	10	64	CL	74	1.07	49	21	28
26	0-6	1	19	60	20	MH	80	1.60	55	37	18	06-12	5	10	15	70	CH	85	1.02	62	17	45
27	0-6	10	22	48	20	ML	68	3.06	43	31	12	12-18	11	23	48	18	MH	66	2.01	53	33	20
28	0-6	0	97	3	0	SW	3	0.00	-	-	-	12-18	0	96	2	2	SW	4	0.00	-	-	-
29	0-6	2	95	3	0	SW	3	0.50	-	-	-	12-18	0	94	4	2	SW	6	0.62	-	-	-
30	0-6	0	94	1	5	SW	6	0.10	-	-	-	06-12	4	88	6	2	SW	8	0.90	-	-	-
31	0-6	0	94	5	1	SW	6	0.34	-	-	-	12-18	0	96	2	2	SW	4	0.00	-	-	-
32	0-6	2	88	8	2	SW	10	0.00	-	-	-	12-18	2	92	5	1	SW	6	0.20	-	-	-
33	0-6	3	92	4	1	SW	5	0.00	-	-	-	06-12	6	82	9	3	SW	12	0.23	-	-	-
34	0-6	3	91	3	3	SW	6	1.05	-	-	-	12-18	5	86	7	2	SW	9	1.00	-	-	-
35	0-6	1	91	4	4	SW	8	0.95	-	-	-	06-12	6	89	5	0	SW	5	0.80	-	-	-
36	0-6	2	73	23	2	SM	25	2.10	-	-	-	06-12	3	69	22	6	SM	28	1.90	-	-	-
37	0-6	5	70	15	10	SM	25	1.10	-	-	-	06-12	0	64	33	3	SM	36	2.30	-	-	-
38	0-6	3	71	24	2	SM	26	1.50	-	-	-	12-18	2	61	33	4	SM	37	1.90	-	-	-
39	0-6	4	71	25	0	SM	25	1.87	-	-	-	12-18	6	58	26	10	SM	36	1.15	-	-	-
40	0-6	3	37	7	53	CL	60	-	45	23	22		-	-	-	-	-	-	-	-	-	-
41	0-6	2	33	10	55	CL	65	-	42	22	20		-	-	-	-	-	-	-	-	-	-
42	0-6	0	40	52	8	MH	60	2.20	54	40	14	06-12	0	36	51	13	MH	64	1.60	60	40	20
43	0-6	1	28	43	28	MH	71	2.60	79	50	29	06-12	3	30	42	25	MH	67	1.10	53	41	12
44	0-6	6	30	50	14	MH	64	0.95	53	30	23	06-12	8	12	58	22	MH	80	0.50	61	39	22
45	0-6	6	15	12	67	CH	79	3.10	65	25	40	06-12	0	20	60	20	MH	80	0.30	70	45	25
46	0-6	2	15	76	7	MH	83	2.75	59	44	15	12-18	5	15	20	60	CL	80	2.60	48	22	26
47	0-6	2	35	56	7	MH	63	1.70	60	40	20	06-12	3	26	59	12	MH	71	0.83	52	37	15
48	0-6	0	48	32	20	ML	52	2.30	40	30	10	12-18	0	35	40	25	ML	65	1.10	39	28	11
49	0-6	2	41	49	8	MH	57	1.30	60	48	12	12-18	0	29	55	16	MH	71	0.49	50	35	15
50	0-6	5	21	50	24	MH	74	2.06	55	40	15	06-12	2	24	48	26	MH	74	0.71	53	38	15
51	0-6	1	25	17	57	CL	74	1.98	48	22	26	06-12	3	28	29	40	CL	69	1.07	42	20	22
52	0-6	0	35	45	20	MH	65	1.50	51	40	11	12-18	0	30	48	22	MH	70	0.75	56	43	13
53	0-6	0	33	50	17	MH	67	1.03	62	50	12	12-18	2	30	61	7	MH	69	0.82	56	42	14

a/ MH = Inorganic silts, elastic silts.
CH = Organic clays of high plasticity, organic silts.
ML = Inorganic silts.
CL = Inorganic clays of low to medium plasticity.
CH = Inorganic clays of high plasticity, fat clays.
SW = Coastal sands.
OL = Organic silts and organic silty clays of low plasticity.

b/ LL = Liquid limit
PL = Plastic limit
PI = Plastic index

TABLE C-5. CRATER BLOWOUT DATA

	DISTANCE FROM DETONATION								
	3 METERS			6 METERS			9 METERS		
CRATER	MAT WT (G)	VEG (%)	SOIL (%)	MAT WT (G)	VEG (%)	SOIL (%)	MAT WT (G)	VEG (%)	SOIL (%)
1	3005	25	75	1446	6	94	624	9	91
2	1673	12	88	510	11	89	227	12	88
3	4082	29	71	1106	5	95	170	17	83
4	5216	8	92	680	12	88	454	25	75
5	1219	12	88	567	5	95	170	17	83
6	3260	18	82	482	29	71	369	38	62
7	3118	2	98	737	8	92	397	7	93
8	2070	3	97	425	7	93	198	14	86
9	1644	2	98	567	20	80	170	17	83
10	851	47	53	822	52	48	425	80	20
11	1559	55	45	454	37	63	312	64	36
12	936	70	30	369	62	38	227	75	25
13	2892	16	84	851	20	80	227	62	38
14	1361	44	56	454	50	50	227	50	50
15	1134	42	58	340	75	25	170	83	17
16	1701	7	93	737	15	85	312	27	73
17	1531	7	93	397	14	86	227	25	75
18	1786	6	94	340	50	50	170	50	50
19	1134	20	80	482	59	41	340	33	67
20	510	50	50	198	29	71	142	80	20
21	794	14	86	340	83	17	170	83	17
22	2466	15	85	624	27	73	255	56	44
23	1786	30	70	510	33	67	170	67	33
24	2041	28	72	737	54	46	170	67	33
25	1503	8	92	397	7	93	284	20	80
26	1077	16	84	227	25	75	142	0	100
27	595	19	81	794	36	64	170	83	17
28	2892	0	100	454	0	100	227	0	100
29	1644	3	97	510	11	89	113	0	100
30	2381	0	100	567	15	85	113	50	50
31	5528	2	98	482	24	76	142	60	40
32	1843	0	100	198	29	71	170	33	67
33	4082	7	93	567	40	60	170	33	67
34	567	0	100	737	46	54	227	50	50
35	1332	17	83	737	62	38	142	60	40
36	2041	25	75	482	41	59	227	62	38
37	1474	35	65	227	50	50	142	60	40
38	5330	34	66	340	17	83	284	60	40
39	2466	40	60	709	68	32	227	50	50

40 - 53 DATA NOT COLLECTED FOR RED CLAY AND TUBE-DELIVERED ROUNDS.

TABLE C-6. MATRIX OF CORRELATION COEFFICIENTS FOR TNT DATA FROM EMPIRE RANGE 6 AND MINDI FARM SITES

Variable	Crater Volume (m^3)	Crater Depth (m)	Obscured Area Seconds After Detonation (m^2): 1	2	5	10	20	Material Weight (g): at 3m	at 6m	at 9m
Cone Index (kg/cm^2)										
Surface Layer	-0.847 a/	-0.830 a/	0.421	0.432	0.607	0.601	0.490	-0.773 a/	-0.578	-0.347
50 mm Layer	-0.825 a/	-0.775 a/	0.432	0.433	0.628	0.588	0.559	-0.842 a/	-0.456	-0.348
150 mm Layer	-0.802 a/	-0.783 a/	0.415	0.479	0.654	0.588	0.436	-0.779 a/	-0.428	-0.476
Moisture Content Surface (%)	0.787 a/	0.774 a/	-0.445	-0.525	-0.691 a/	-0.592 a/	-0.428	0.780 a/	0.401	0.569
Density Dry (kg/m^3)	-0.649	-0.729 a/	0.224	0.358	0.458	0.427	0.177	-0.601	-0.362	-0.581
Density Wet (kg/m^3)	0.563	0.411	-0.582	-0.525	-0.689 a/	-0.547	0.601	0.586	0.269	0.137
Fines (%)										
Gravels (%)	-0.046	0.035	0.119	-0.003	0.205	0.388	0.429	-0.262	0.229	-0.413
Sands (%)	-0.657	-0.632	0.138	0.327	0.381	0.025	0.014	-0.730 a/	-0.253	-0.337
Silts (%)	0.484	0.398	-0.195	-0.219	-0.434	-0.350	-0.377	0.719 a/	-0.025	0.582
Clays (%)	-0.326	-0.100	0.427	0.298	0.433	0.474	0.487	-0.067	-0.301	0.156
Atterburg Limits (%)	0.085	0.087	-0.122	-0.165	-0.046	0.101	0.131	-0.206	0.375	-0.466
Liquid Limit										
Top Soil Layer (0 to 150 mm)	0.110	0.119	0.013	-0.113	-0.215	-0.278	-0.037	0.109	-0.245	0.110
Bottom of Crater	0.205	0.315	0.063	0.237	0.151	-0.449	-0.314	0.035	0.314	-0.427
Plastic Limit										
Top Soil Layer (0 to 150 mm)	0.326	0.334	-0.096	-0.273	-0.385	-0.251	-0.109	0.423	-0.119	0.499
Bottom of Crater	0.603	0.656	0.170	0.232	0.072	-0.229	-0.253	0.593	0.431	-0.111
Plastic Index										
Top Soil Layer (0 to 150 mm)	-0.160	-0.153	0.129	0.047	0.035	-0.225	-0.051	-0.269	-0.311	-0.350
Bottom of Crater	-0.576	-0.535	-0.157	-0.063	0.058	-0.155	0.012	-0.735 a/	-0.242	-0.286
Temperature (°C)										
1 Meter	-0.286	-0.345	0.174	0.260	0.421	0.523	0.360	-0.402	0.105	-0.687 a/
2 Meters	-0.367	-0.406	0.324	0.362	0.546	0.676 a/	0.529	-0.480	0.036	-0.672 a/
4 Meters	-0.347	-0.370	0.309	0.326	0.525	0.667 a/	0.549	-0.460	0.031	-0.658
Relative Humidity (%)	0.464	0.471	-0.125	-0.083	-0.351	-0.670 a/	-0.474	0.522	0.083	0.456
Windspeed (knots)										
1 Meter	-0.435	-0.423	0.450	0.586	0.667	0.352	0.265	-0.584	-0.120	-0.934 a/
2 Meters	-0.496	-0.509	0.526	0.646	0.749 a/	0.556	0.390	-0.565	-0.146	-0.872 a/
4 Meters	-0.142	-0.132	0.312	0.468	0.532	0.223	0.210	-0.346	0.196	-0.927 a/
Material Weight (g)										
3 Meters	0.916 a/	0.894 a/	-0.339	-0.362	-0.493	-0.341	-0.416	1.000 a/	0.567	0.381
6 Meters	0.788 a/	0.767 a/	-0.476	-0.362	-0.367	-0.281	-0.422	0.567	1.000 a/	-0.192
9 Meters	0.178	0.201	-0.155	-0.324	-0.407	-0.187	-0.067	0.381	-0.192	1.000 a/

a/ Significantly different from zero at the α=.05 level

TABLE C-7. MATRIX OF CORRELATION COEFFICIENTS FOR 105-MILLIMETER DATA FROM EMPIRE RANGE 6 AND MINDI FARM SITES

Variable	Crater Volume (m^3)	Crater Depth (m)	Obscured Area Seconds After Detonation (m^2) 1	2	5	10	20	Material Weight (g) at 3m	at 6m	at 9m
Cone Index (kg/cm^2)										
Surface Layer	-0.857 a/	-0.610	0.356	0.449	0.686 a/	0.318	0.038	0.544	-0.685 a/	-0.175
50 mm Layer	-0.973 a/	-0.641	0.364	0.523	0.671 a/	0.336	0.081	-0.393	-0.465	0.153
150 mm Layer	-0.849 a/	-0.868 a/	0.427	0.620	0.831 a/	0.645	0.375	-0.394	-0.494	0.064
Moisture Content Surface (%)	0.841 a/	0.893 a/	-0.482	-0.662	-0.846 a/	-0.703 a/	-0.445	0.306	0.494	-0.104
Density Dry (kg/m^3)	-0.298	-0.606	0.063	0.122	0.402	0.800 a/	0.798 a/	-0.131	-0.335	0.125
Density Wet (kg/m^3)	0.555	0.242	-0.653	-0.617	-0.442	-0.245	0.535	0.154	0.105	0.028
Fines (%)										
Gravels (%)	-0.096	0.007	-0.321	-0.006	0.106	0.227	-0.035	0.231	-0.247	-0.346
Sands (%)	-0.809 a/	-0.444	0.584	0.711 a/	0.587	0.326	0.112	0.120	-0.145	0.600
Silts (%)	0.430	0.177	0.075	-0.289	-0.348	-0.359	-0.012	-0.278	0.184	0.093
Clays (%)	0.473	0.231	-0.037	-0.409	-0.421	-0.265	0.078	-0.063	-0.229	0.029
Atterburg Limits (%)	-0.427	-0.185	-0.109	0.331	0.389	0.315	-0.079	0.152	0.079	-0.174
Liquid Limit										
Top Soil Layer (0 to 150 mm)	0.101	0.373	-0.195	0.081	0.029	0.218	0.000	0.493	0.662	0.035
Bottom of Crater	0.473	0.333	-0.487	-0.360	-0.211	-0.176	-0.286	-0.164	0.091	-0.695 a/
Plastic Limit										
Top Soil Layer (0 to 150 mm)	0.221	0.382	-0.117	-0.453	0.507	-0.443	-0.059	-0.114	0.074	0.400
Bottom of Crater	0.463	0.499	-0.144	-0.322	-0.432	-0.322	-0.124	0.152	0.305	-0.257
Plastic Index										
Top Soil Layer (0 to 150 mm)	-0.100	-0.067	-0.023	0.357	0.367	0.422	0.041	0.340	0.300	-0.258
Bottom of Crater	-0.099	-0.225	-0.197	0.048	0.247	0.171	-0.080	-0.246	-0.214	-0.234
Temperature (°C)										
1 Meter	-0.712 a/	-0.327	0.403	0.228	0.430	0.045	-0.010	-0.678 a/	-0.556	-0.038
2 Meters	-0.746 a/	-0.369	0.305	0.219	0.437	0.054	-0.065	-0.626	-0.698 a/	-0.128
4 Meters	-0.760 a/	-0.678 a/	0.337	0.353	0.625	0.431	0.305	-0.587	-0.649	0.056
Relative Humidity (%)	0.770 a/	0.605	-0.164	-0.351	-0.585	-0.520	-0.351	0.358	0.358	-0.244
Wind Speed (Knots)										
1 Meter	-0.315	-0.359	-0.435	-0.0[illegible]	0.138	0.233	0.068	-0.207	-0.269	0.047
2 Meters	-0.858 a/	-0.492	0.266	0.528	0.604	0.156	-0.228	-0.266	-0.390	-0.171
4 Meters	-0.854 a/	-0.296	0.322	0.438	0.475	0.109	-0.145	-0.163	-0.352	-0.047
Material Weight (g)										
3 Meters	0.298	0.261	-0.112	0.011	-0.209	0.147	0.113	1.000 a/	0.652	0.462
6 Meters	0.406	0.465	-0 069	0.025	-0.235	-0.010	0.001	0.652	1.000 a/	0.433
9 Meters	-0.184	0.208	0.109	0.195	0.003	0.278	0.431	0.462	0.433	1.000 a/

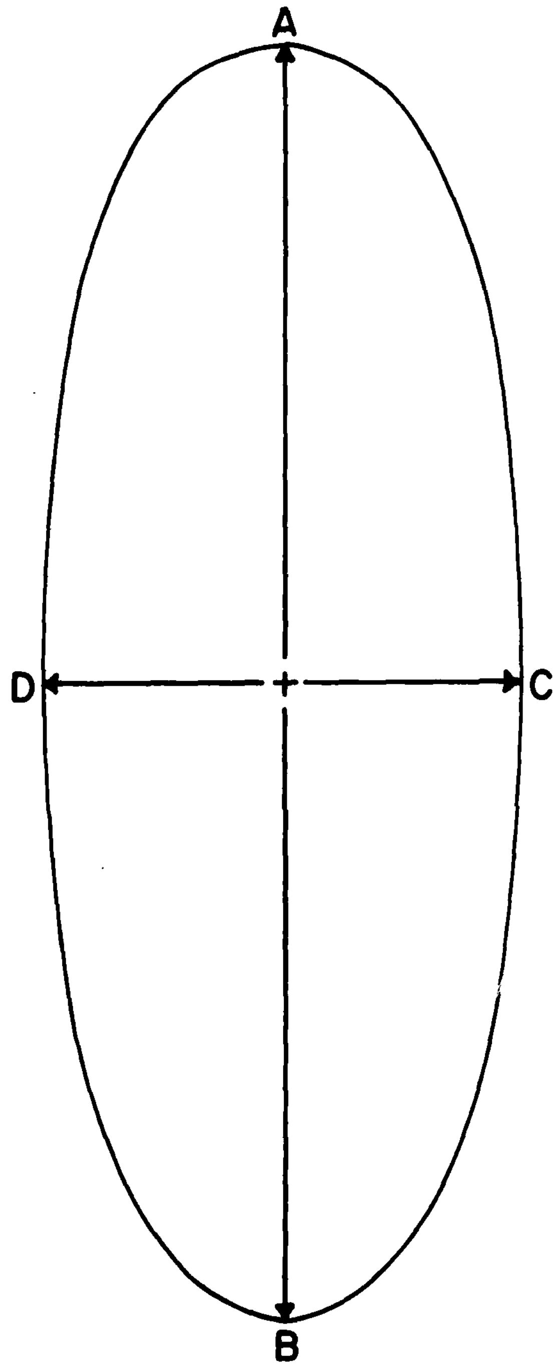
a/ Significantly different from zero at the α=.05 level

TABLE C-8. MATRIX OF CORRELATION COEFFICIENTS FOR 155-MILLIMETER DATA FROM EMPIRE RANGE 6 AND MINDI FARM SITES

Variable	Crater Volume (m^3)	Crater Depth (m)	Obscured Area Seconds After Detonation (m^2) 1	2	5	10	20	Material Weight (g) at 3m	at 6m	at 9m
Cone Index (kg/cm^2)										
Surface Layer	-0.353	-0.361	0.087	0.699	0.888 a/	0.672	0.707 a/	-0.650	-0.558 a/	-0.744 a/
50 mm Layer	-0.373	-0.506	0.038	0.752 a/	0.859 a/	0.552	0.536	-0.688 a/	-0.588	0.671 a/
150 mm Layer	-0.649	-0.507	0.364	0.896 a/	0.781 a/	0.805 a/	0.783 a/	-0.777 a/	-0.274	-0.574
Moisture Content Surface (%)	0.672 a/	0.548	-0.455	-0.934 a/	-0.793 a/	-0.852 a/	-0.831 a/	0.750 a/	0.257	0.628
Density Dry (kg/m^3)	-0.355	-0.690 a/	0.417	0.713 a/	0.584	0.871 a/	0.778 a/	-0.327	-0.289	-0.461
Density Wet (kg/m^3)	0.444	-0.092	-0.100	-0.364	-0.351	-0.097	-0.180	0.574	0.007	0.286
Fines (%)	0.091	-0.254	-0.223	0.321	0.212	0.480	0.413	-0.142	-0.342	-0.132
Gravels (%)	-0.079	0.091	0.234	0.434	0.461	0.446	0.603	-0.167	-0.211	-0.709 a/
Sands (%)	-0.133	-0.056	0.175	-0.416	-0.467	-0.617	-0.670	0.180	0.510	0.574
Silts (%)	-0.063	0.600	0.029	-0.533	-0.348	-0.202	-0.109	0.054	0.382	0.289
Clays (%)	0.115	-0.545	-0.136	0.492	0.347	0.278	0.183	-0.069	-0.445	-0.278
Atterburg Limits (%)										
Liquid Limit										
Top Soil Layer (0 to 150 mm)	0.693 a/	0.455	-0.272	-0.642	-0.733 a/	-0.602	-0.526	0.865 a/	0.336	0.409
Bottom of Crater	0.462	0.688 a/	-0.233	-0.766 a/	-0.746 a/	-0.818 a/	-0.726 a/	0.593	0.380	0.430
Plastic Limit										
Top Soil Layer (0 to 150 mm)	0.428	0.598	-0.197	-0.865 a/	0.776 a/	-0.678	-0.631	0.694 a/	0.590	0.732 a/
Bottom of Crater	-0.101	0.563	0.169	-0.429	-0.514	-0.427	-0.343	0.260	0.777 a/	0.483
Plastic Index										
Top Soil Layer (0 to 150 mm)	0.448	-0.068	-0.112	0.216	-0.008	0.042	0.084	0.376	-0.220	-0.285
Bottom of Crater	0.751 a/	0.160	-0.550	-0.560	-0.423	-0.637	-0.612	-0.442	-0.537	-0.075
Temperature (°C)										
1 Meter	-0.071	-0.245	-0.197	0.580	0.807 a/	0.542	0.573	-0.472	-0.702 a/	-0.762 a/
2 Meters	-0.140	-0.043	-0.175	0.465	0.659	0.326	0.404	-0.469	-0.437	-0.581
4 Meters	-0.243	-0.080	-0.335	0.495	0.612	0.307	0.329	-0.730 a/	-0.565	-0.499
Relative Humidity (%)	0.151	0.041	0.258	-0.515	-0.709 a/	-0.439	-0.508	0.626	0.647	0.715 a/
Wind Speed (Knots)										
1 Meter	0.545	0.674	-0.635	-0.125	0.221	0.056	0.201	0.052	-0.635	-0.512
2 Meters	0.620	0.367	-0.428	-0.094	0.205	0.214	0.363	0.232	-0.631	-0.612
4 Meters	0.525	0.229	-0.627	0.017	0.309	0.154	0.237	0.022	-0.726 a/	-0.529
Material Weight (g)										
3 Meters	0.773 a/	0.388	-0.080	-0.684	-0.761 a/	-0.579	-0.506	1.000 a/	0.252	0.462
6 Meters	-0.321	0.116	0.489	-0.157	-0.554	-0.277	-0.321	0.252	1.000 a/	0.433
9 Meters	0.012	0.218	0.156	-0.525	-0.712 a/	-0.602	-0.706	0.306	0.727 a/	1.000 a/

a/ Significantly different from zero at the α=.05 level

APPENDIX D. GRAPHIC AND PHOTOGRAPHIC DOCUMENTATION OF CRATERS AND CLOUDS



The crater profiles shown in this Appendix are all at the same scale (10-centimeter increments). Crater diameters were measured by laying a survey rod (A to B) across the apparent center of the crater at the original ground level. Vertical distances (from the rod to the crater floor) were recorded at 10-centimeter increments. For asymmetric craters, additional measurements were recorded in the same manner by laying another rod (C to D) perpendicular to the first. In some cases, loose material was scooped out (after the initial measurements) and the true craters were measured to determine the amount of fallback material.

Figure D-1. Crater Measurement Survey Points.

Part D-1. Selected Crater Profiles and Photographs

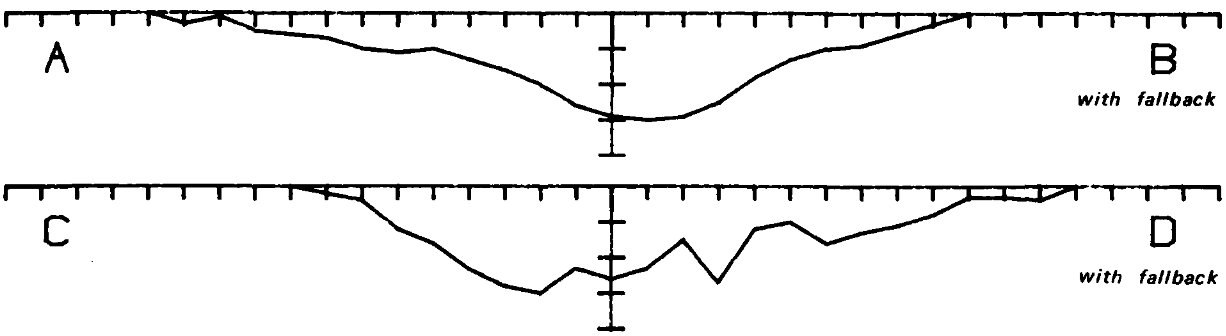


Figure D-2. Crater 7 (Mindi Farm: Bare Soil) Site and Profiles--155mm Round.

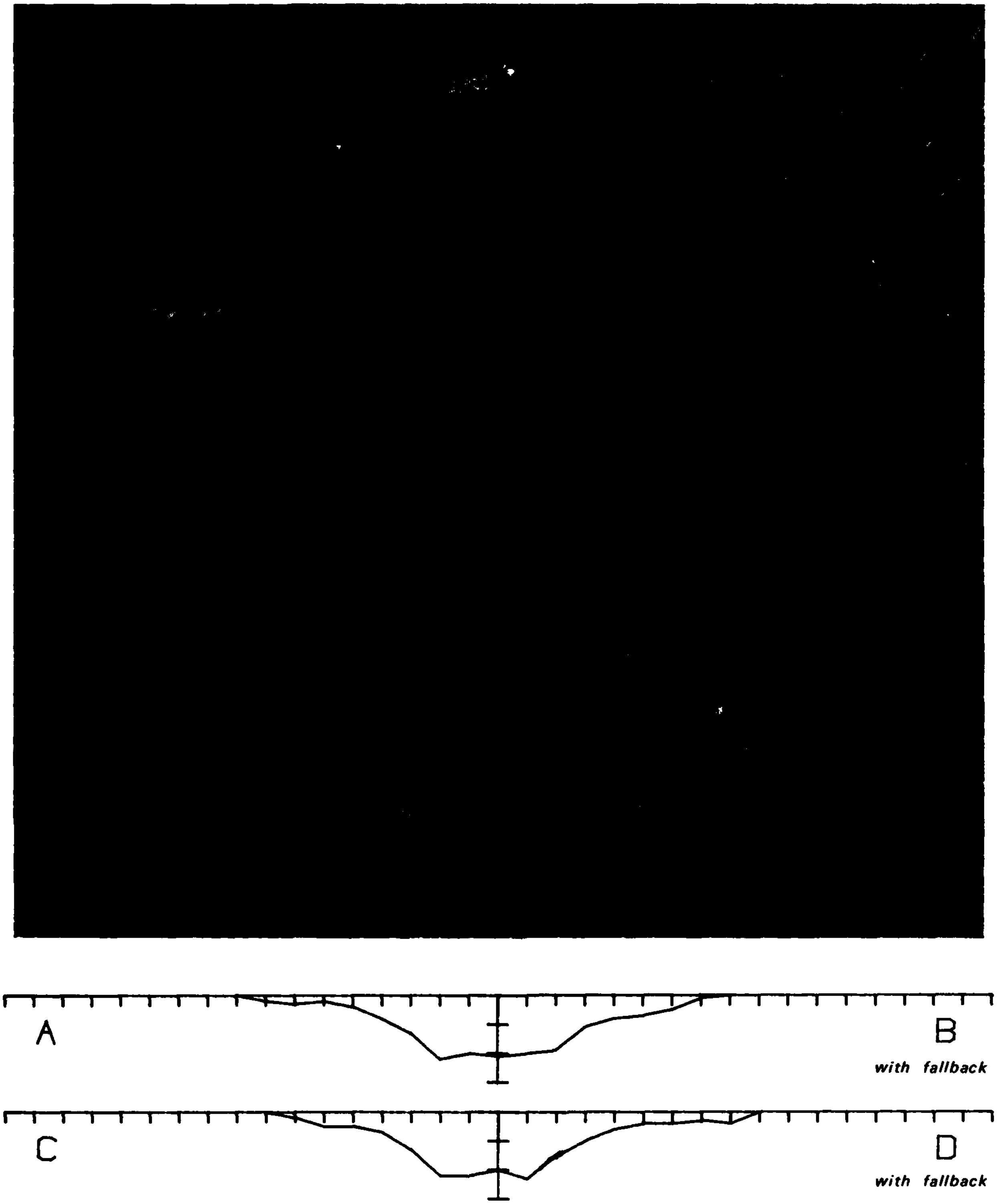


Figure D-3. Crater 18 (Empire Range 6: Bare Soil) Site and Profiles--TNT.

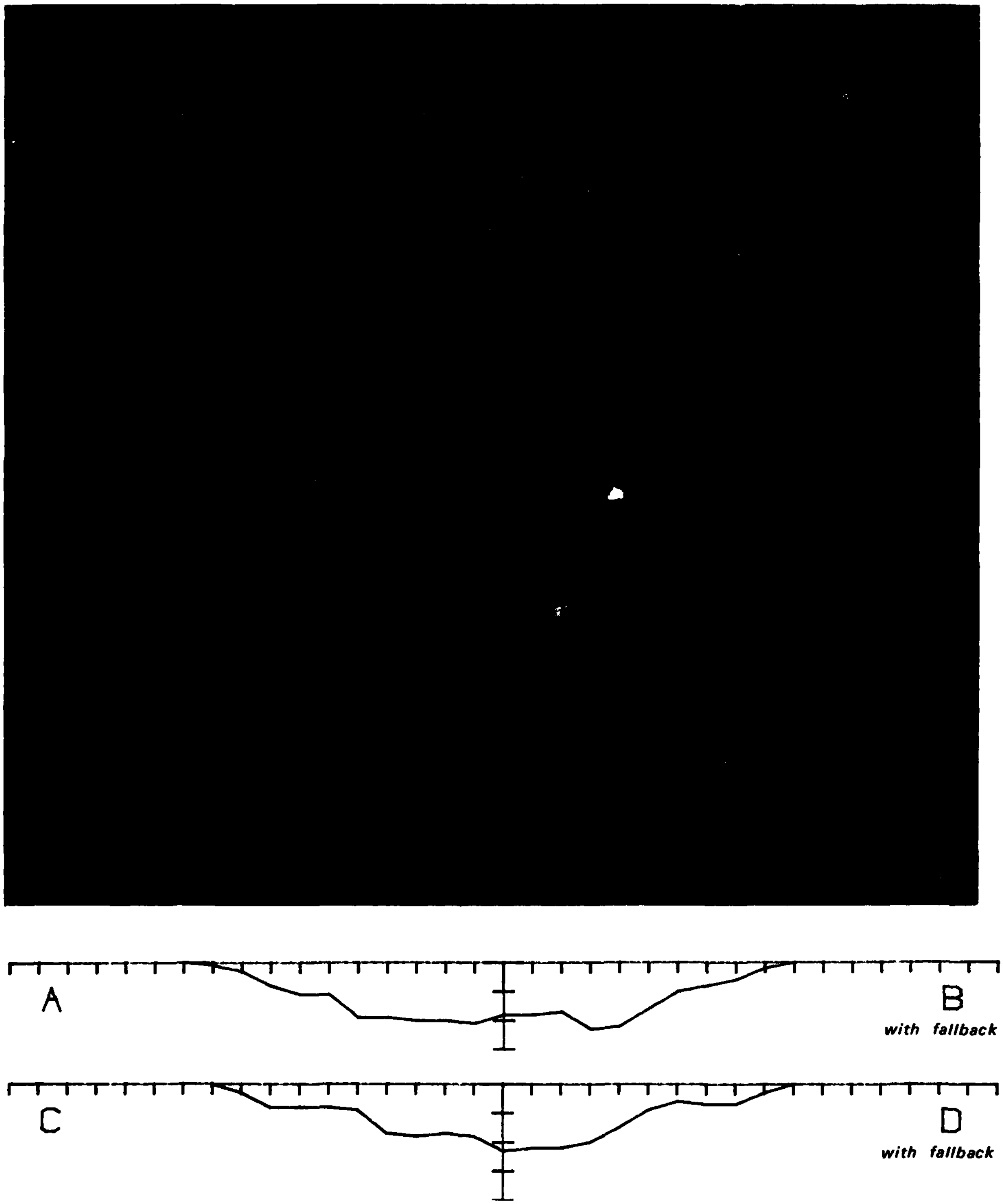


Figure D-4. Crater 25 (Empire Range 6: Bare Soil) Site and Profiles--155mm Round.

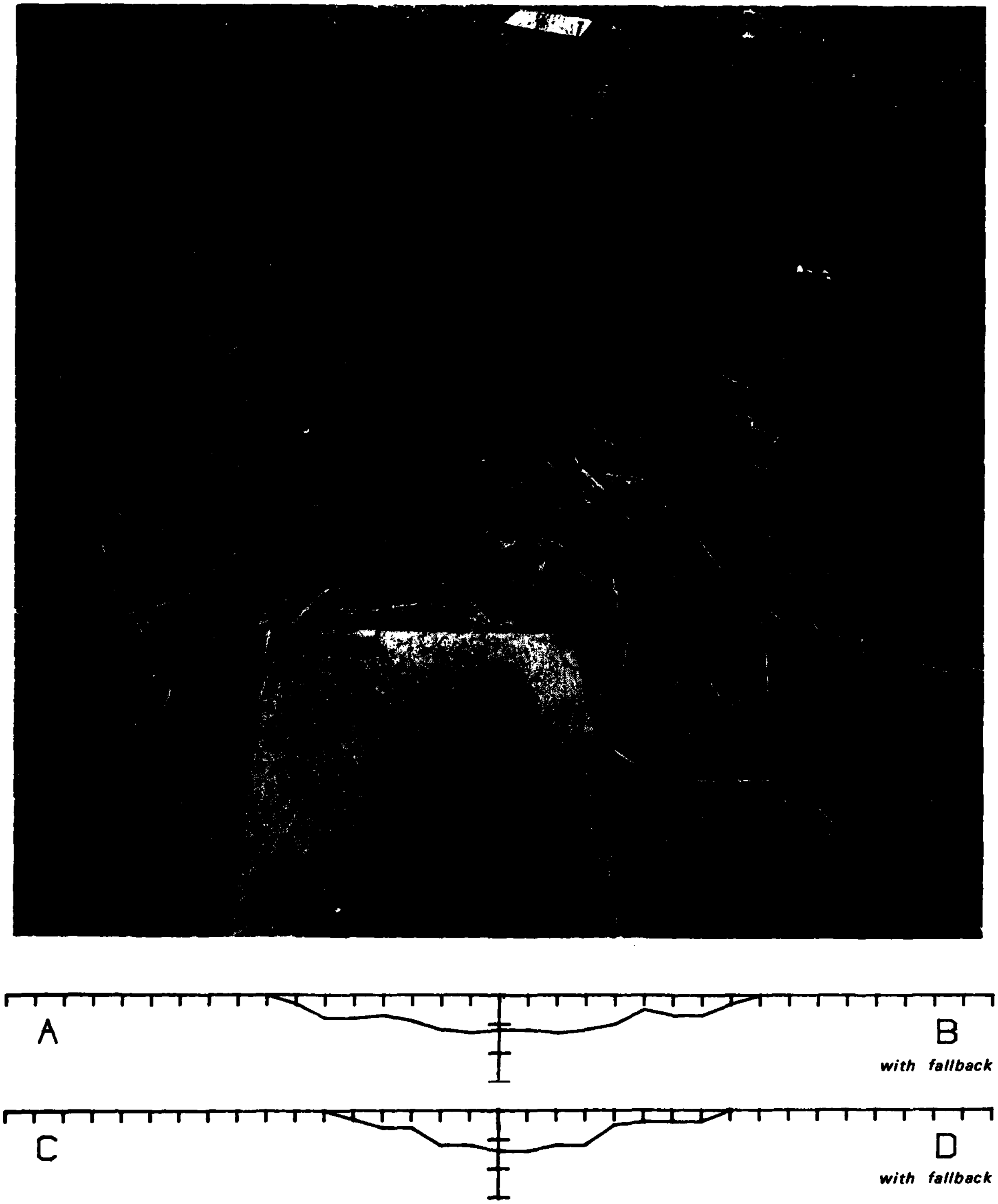


Figure D-5. Crater 26 (Empire Range 6: Bare Soil) Site and Profiles--105mm Round.

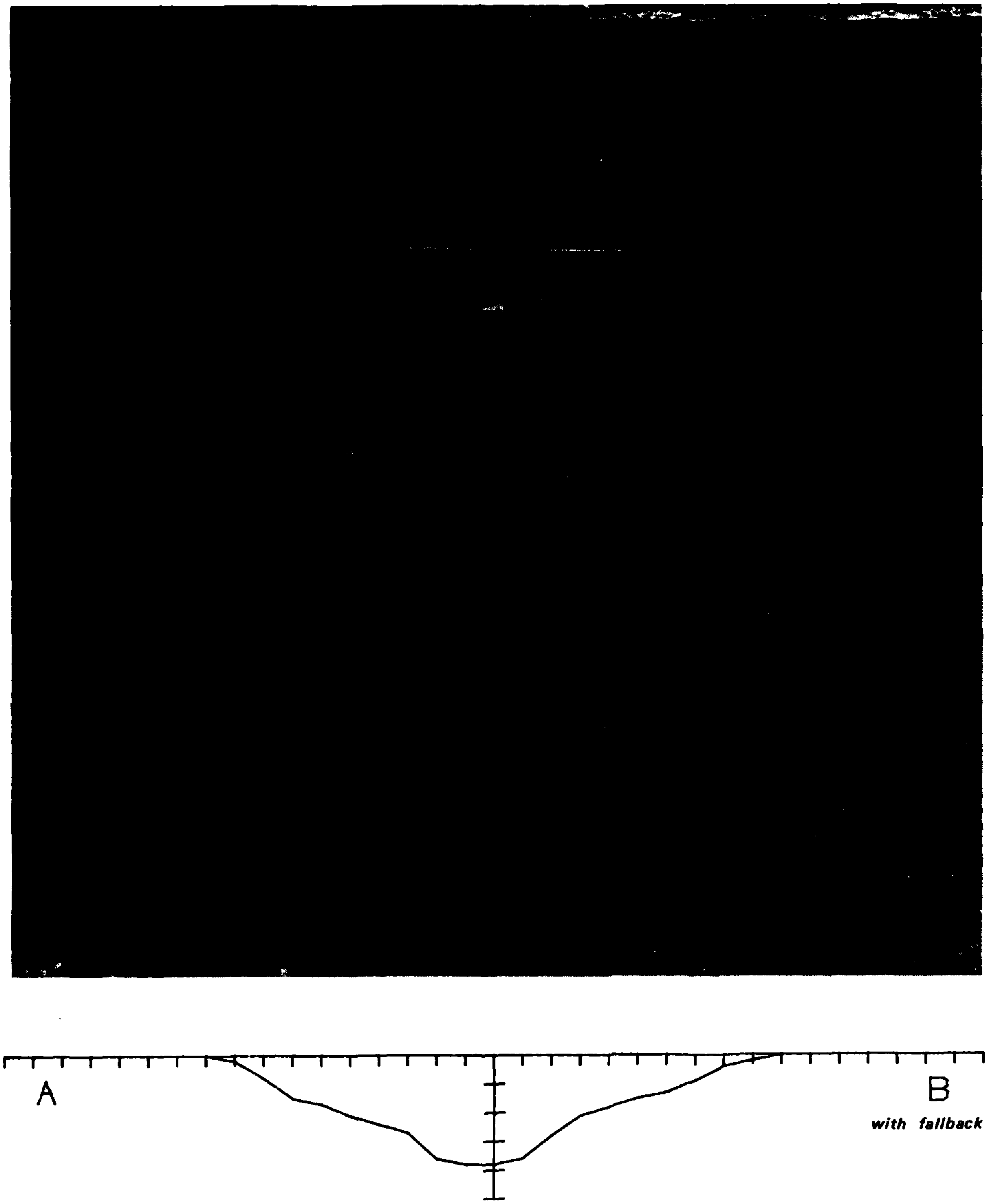
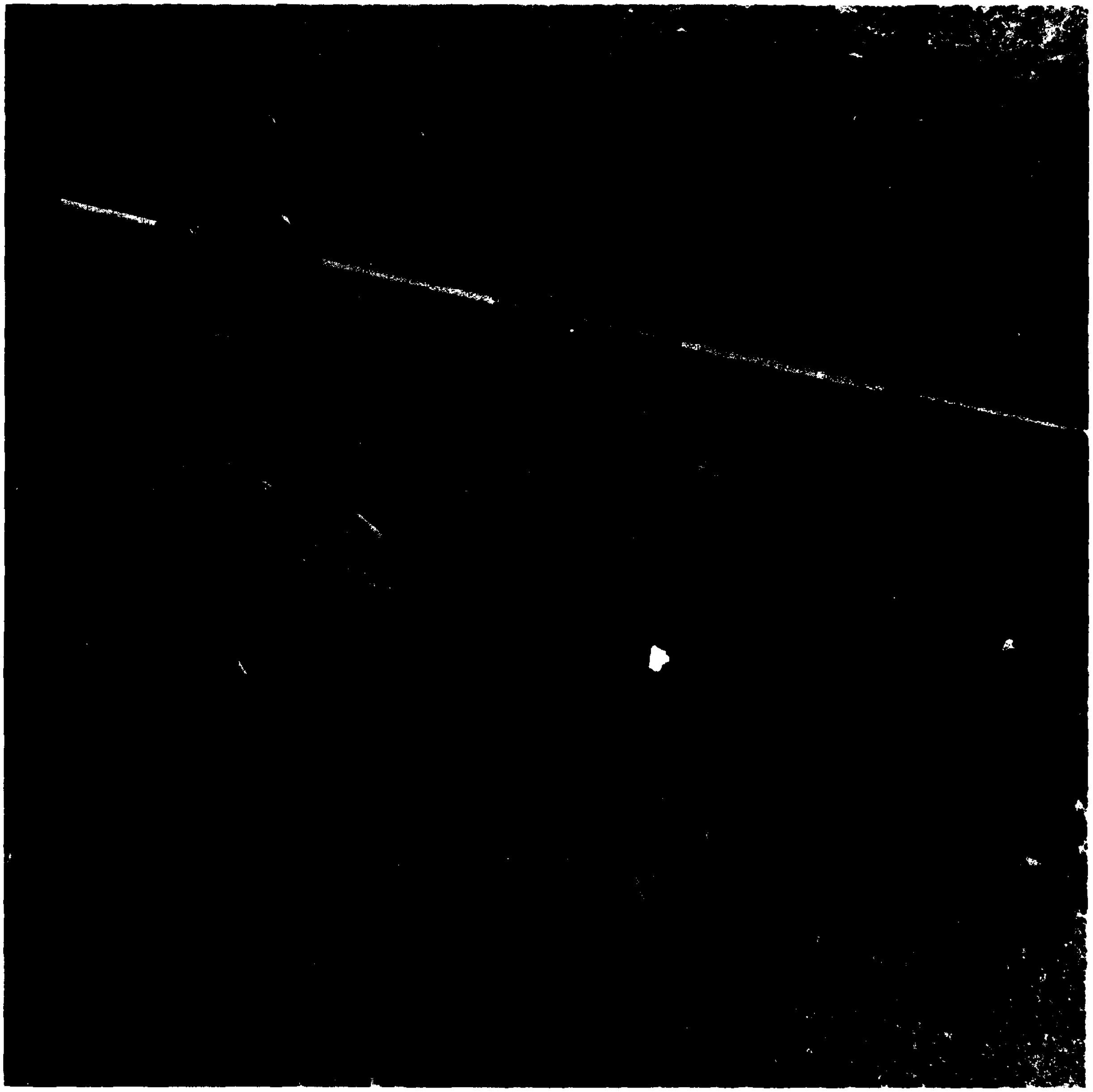


Figure D-6. Crater 32 (Pina Beach: Wet Sand) Site and Profile--TNT.



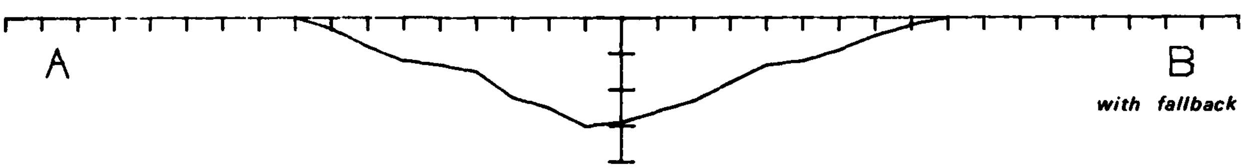


Figure D-7. Crater 33 (Pina Beach: Black Sand) Site and Profile--TNT.

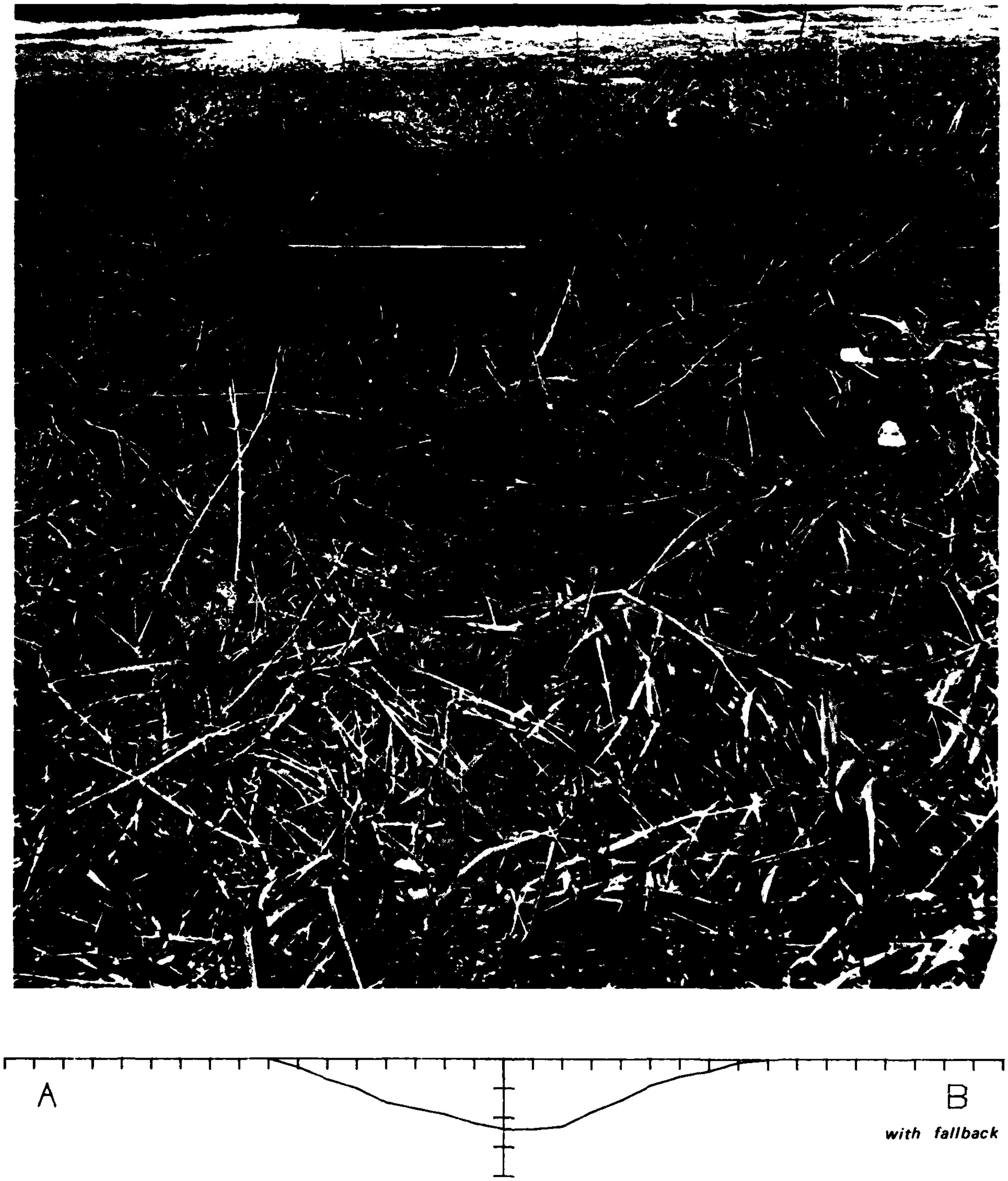


Figure D-8. Crater 36 (Pina Beach: Spider Lily, Wet Sand) Site and Profile--TNT.

Part D-2. Representative With/Without Fallback Profile Comparisons

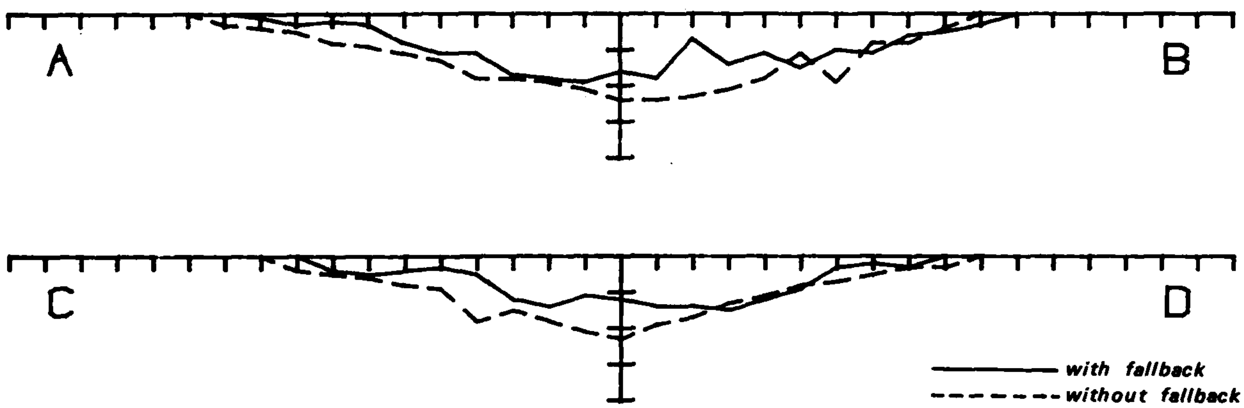


Figure D-9. Crater 2 (105mm--Mindi Farm) Profile Comparisons--
with and without Fallback.

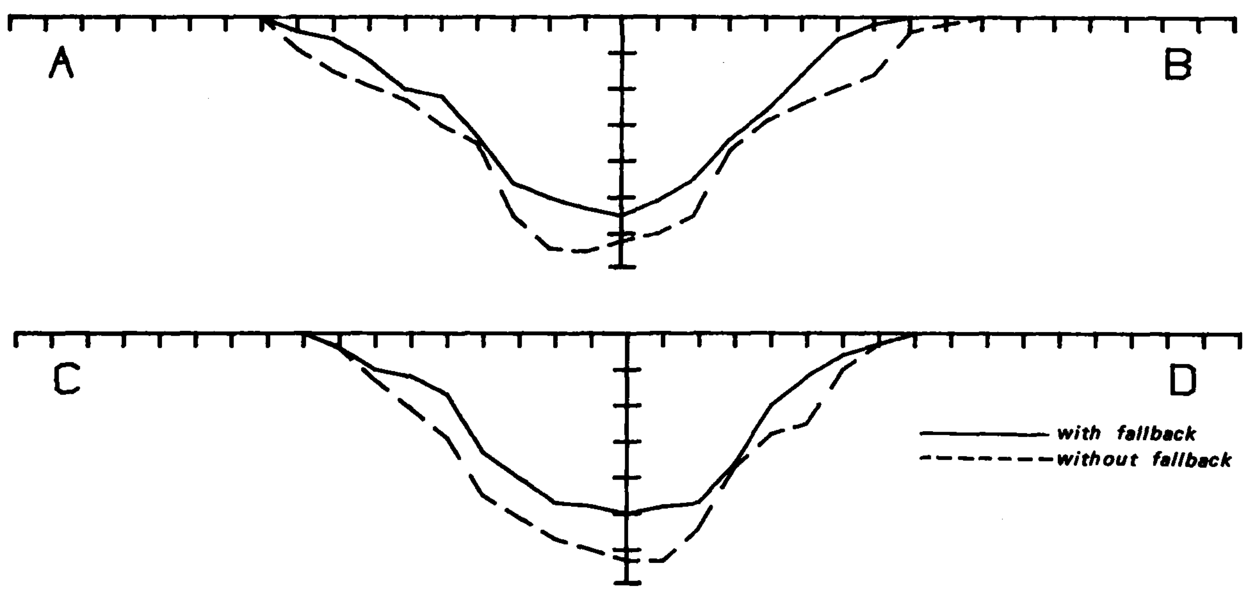


Figure D-10. Crater 3 (TNT--Mindi Farm) Profile Comparisons--
with and without Fallback.

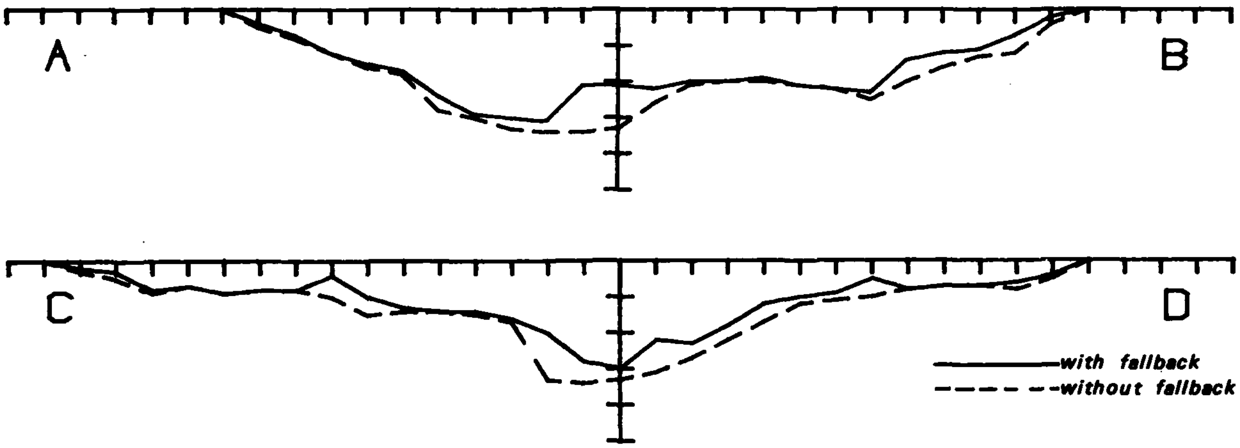


Figure D-11. Crater 4 (155mm--Mindi Farm) Profile Comparisons--with and without Fallback.

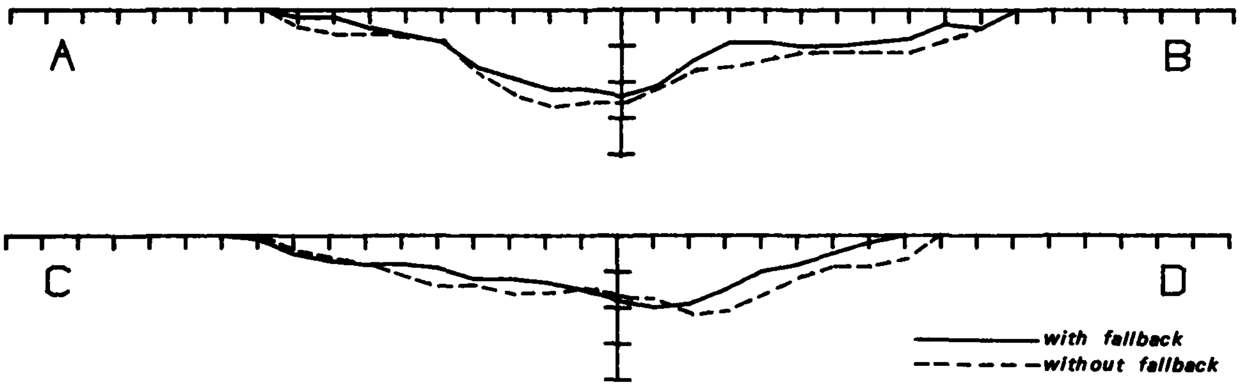


Figure D-12. Crater 16 (155mm--Empire Range 6) Profile Comparisons--with and without Fallback.

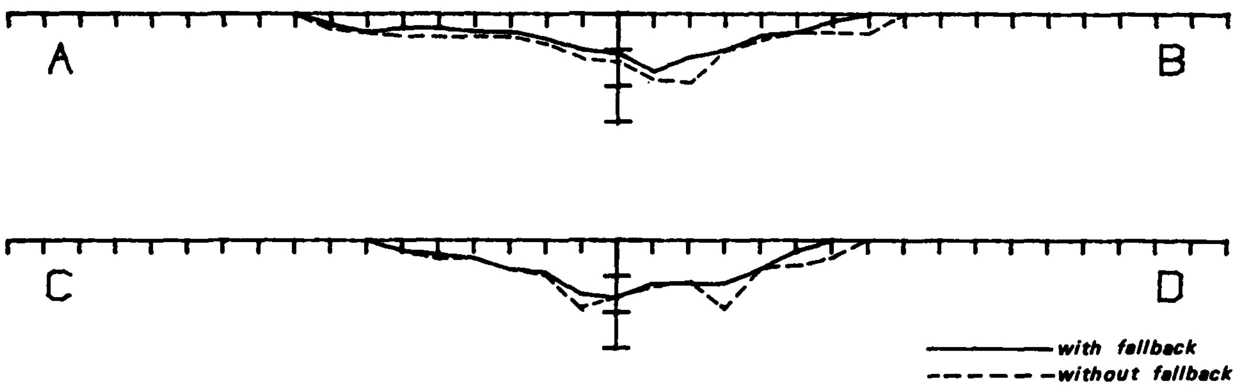


Figure D-13. Crater 20 (105mm--Empire Range 6) Profile Comparisons--with and without Fallback.

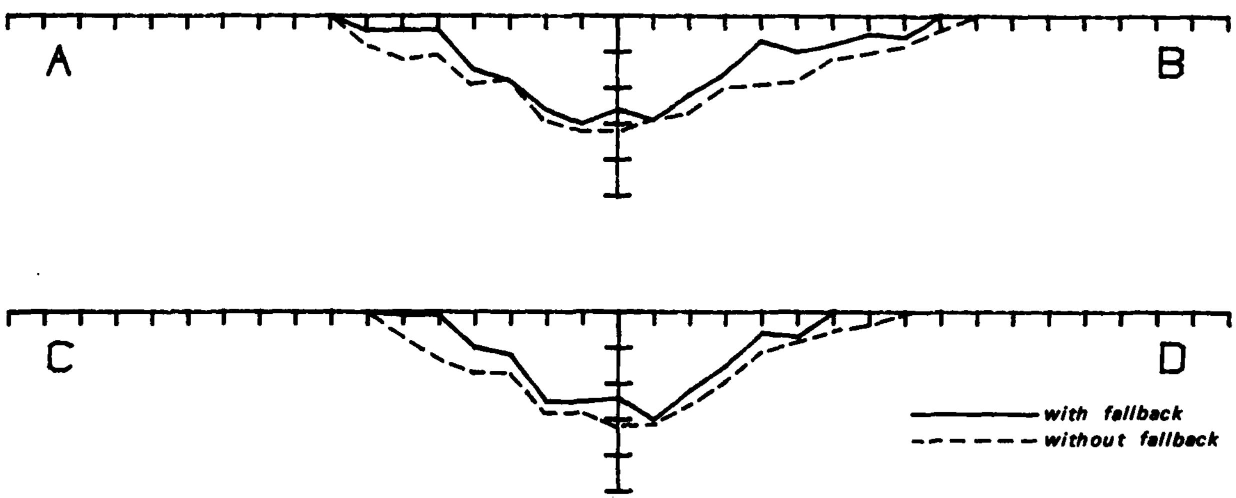


Figure D-14. Crater 24 (TNT--Empire Range 6) Profile Comparisons--with and without Fallback.

Part D-3. Crater Profiles (Craters 1 through 39)

(NOTE: With and without fallback profiles do not necessarily overlap because they were measured from rim to rim instead of from a reference point.

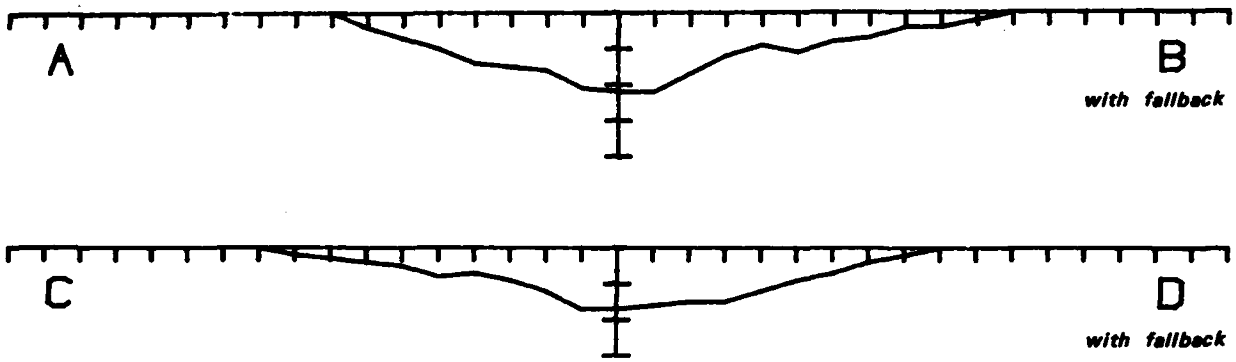


Figure D-15. Crater 1 (Mindi Farm: 155mm).
(Craters 2 through 4--see figures D-9 through D-11.)

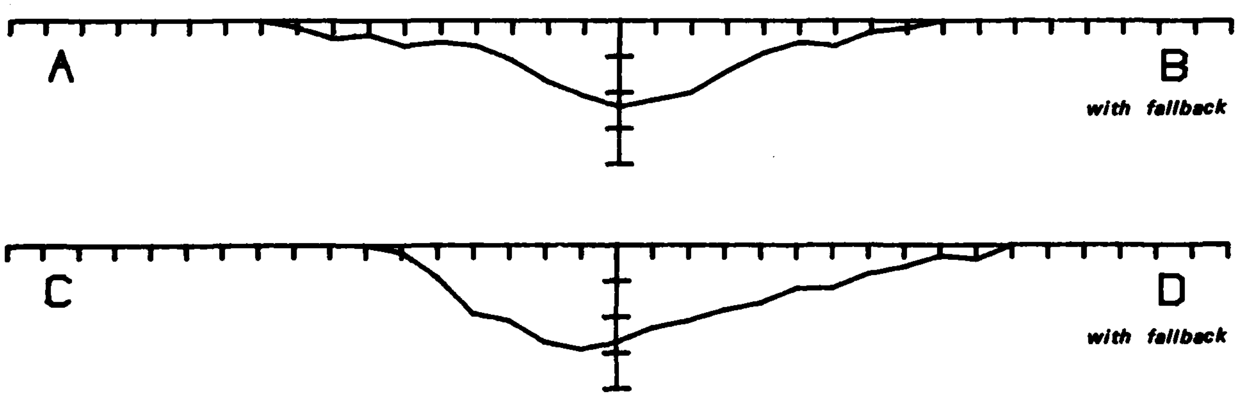


Figure D-16. Crater 5 (Mindi Farm: 105mm).

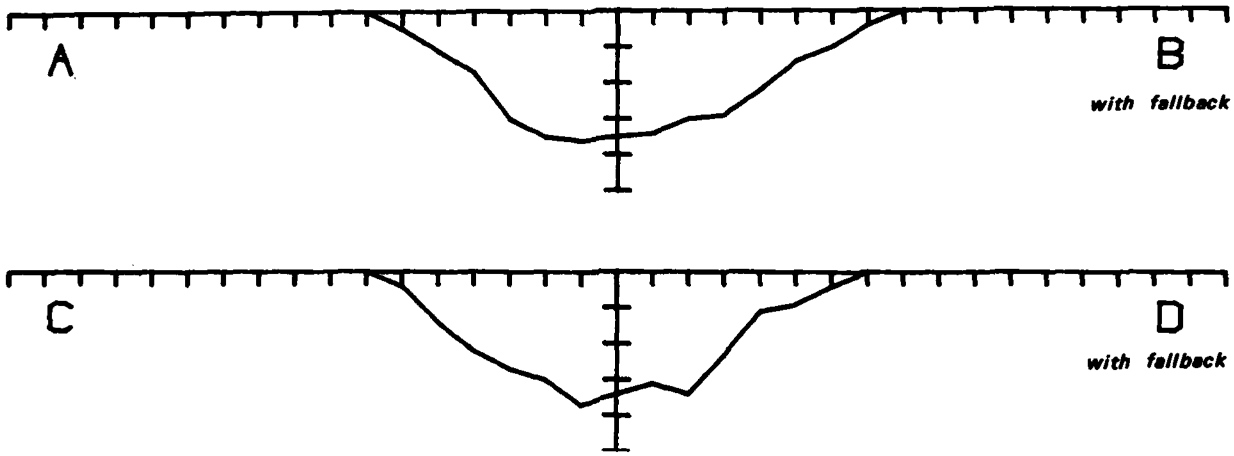


Figure D-17. Crater 6 (Mindi Farm: TNT).

(Crater 7 see figure D-2.)

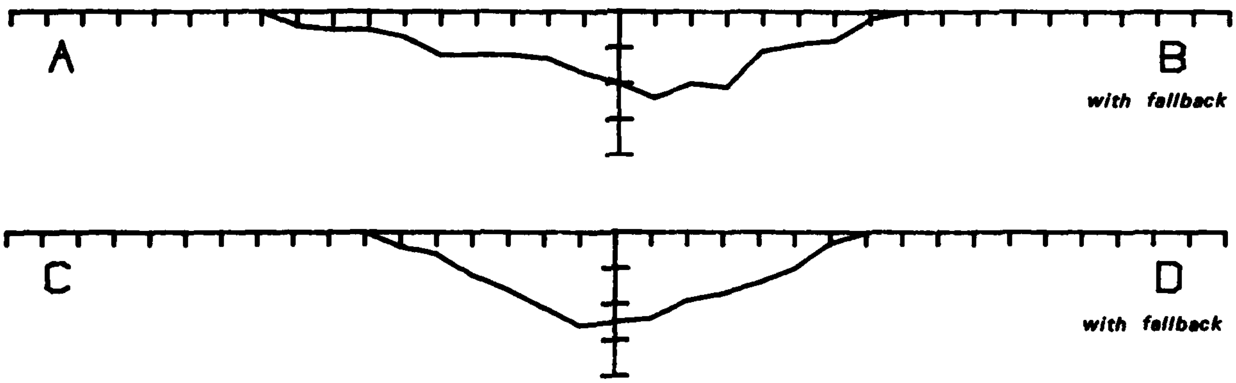


Figure D-18. Crater 8 (Mindi Farm: 105mm).

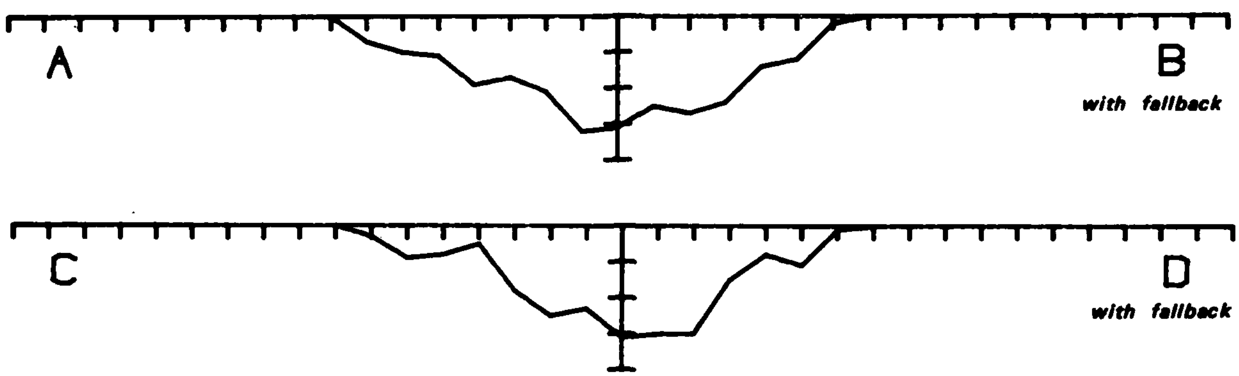


Figure D-19. Crater 9 (Mindi Farm: TNT).

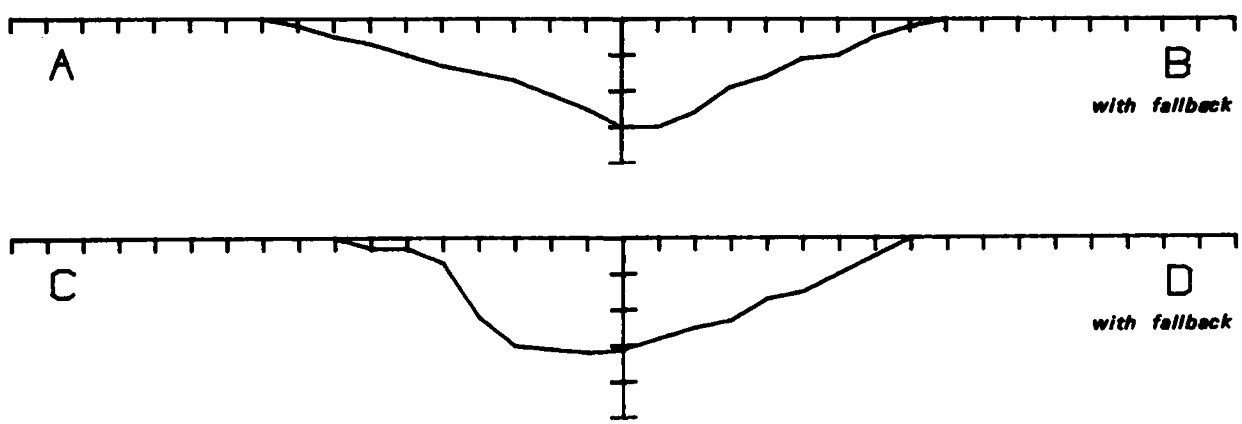


Figure D-20. Crater 10 (Empire Range 6: 155mm).

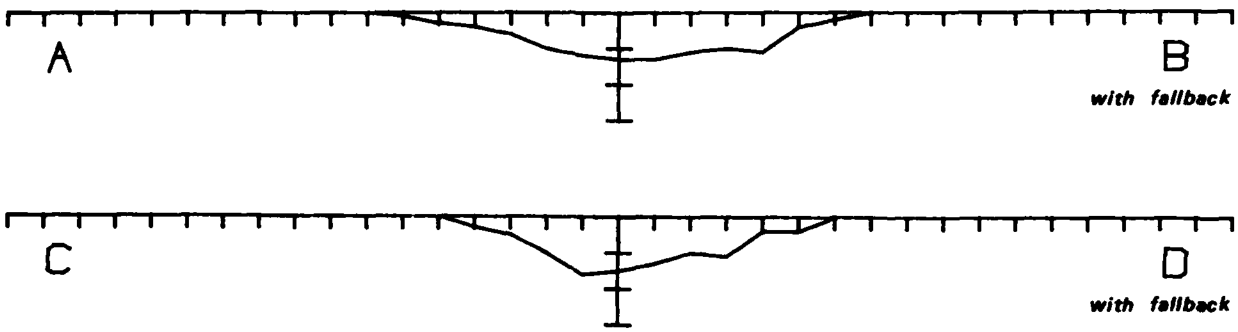


Figure D-21. Crater 11 (Empire Range 6: 105mm).

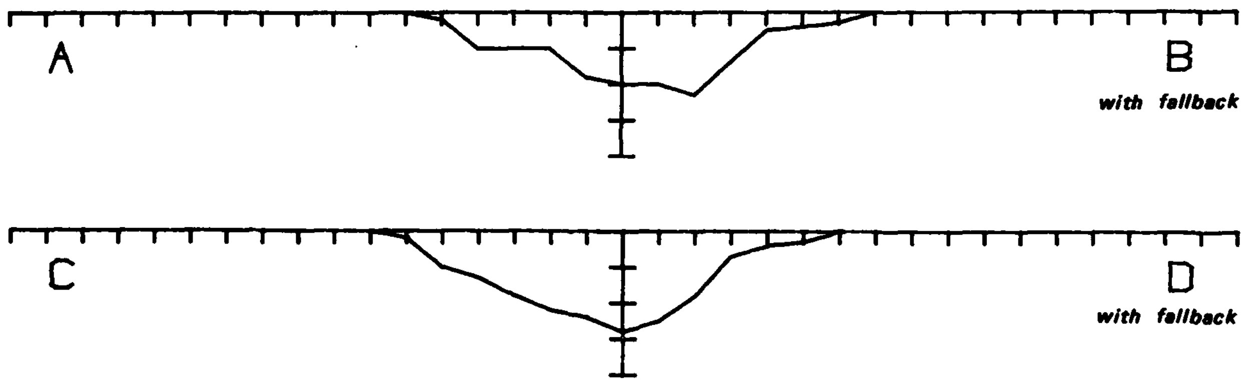


Figure D-22. Crater 12 (Empire Range 6: (TNT).

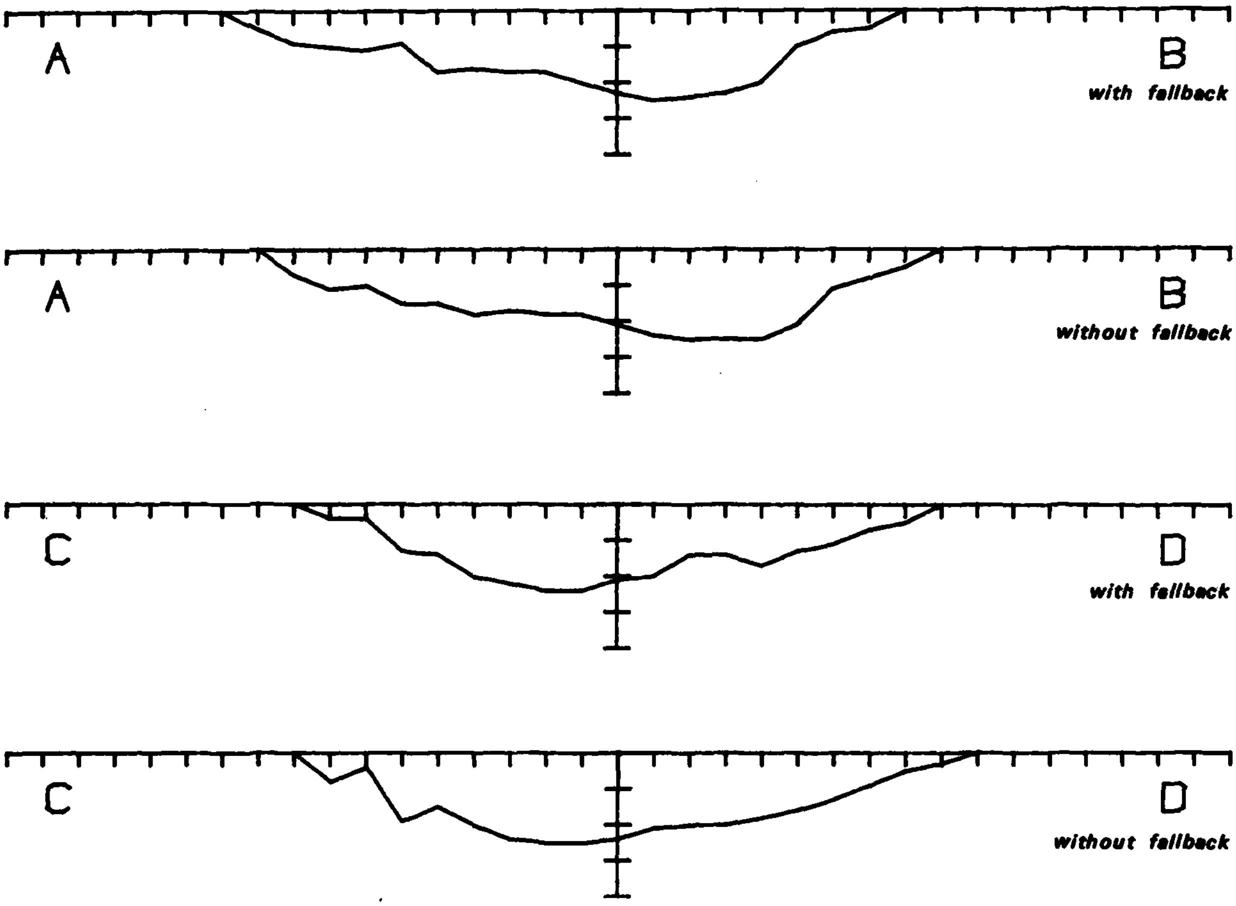


Figure D-23. Crater 13 (Empire Range 6: 155mm).

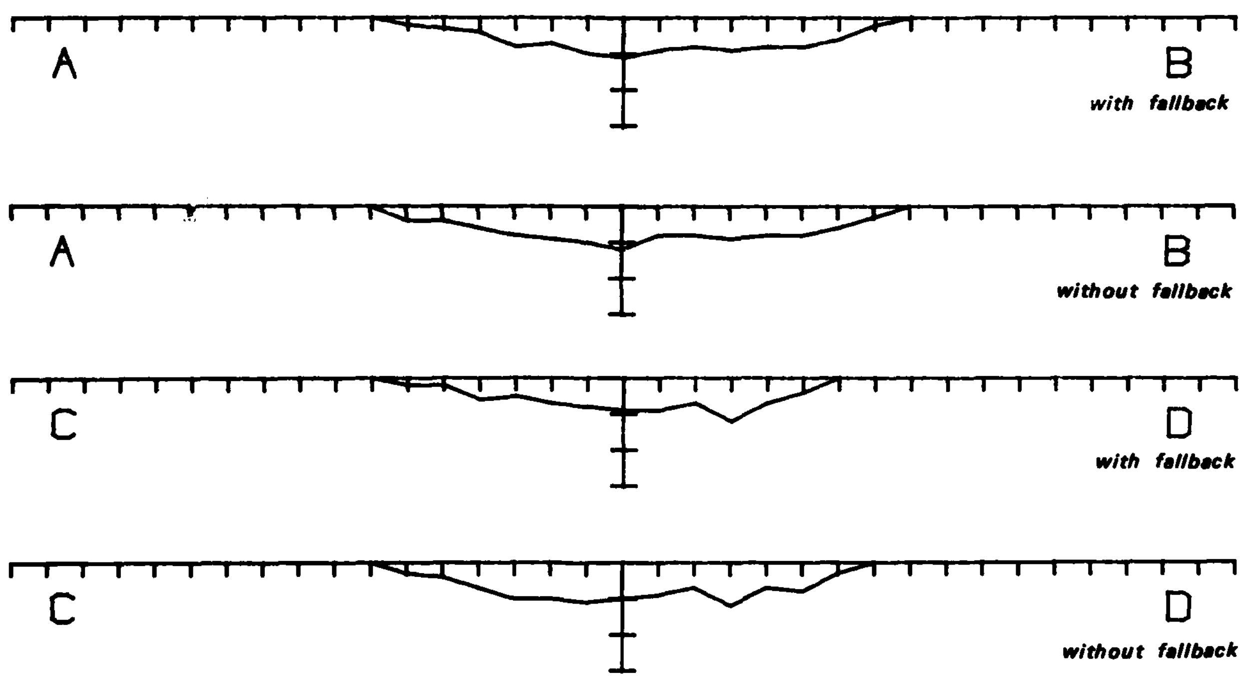


Figure D-24. Crater 14 (Empire Range 6: 105mm).

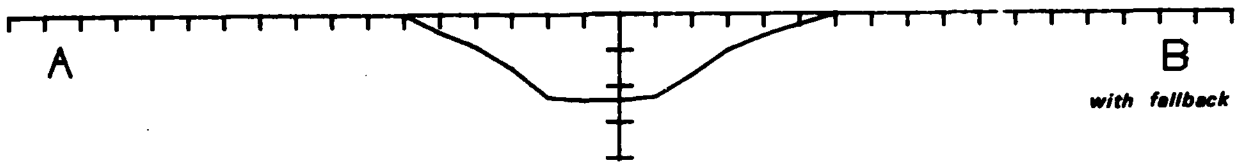


Figure D-25. Crater 15 (Empire Range 6: TNT).

(Crater 16--see figure D-12.)

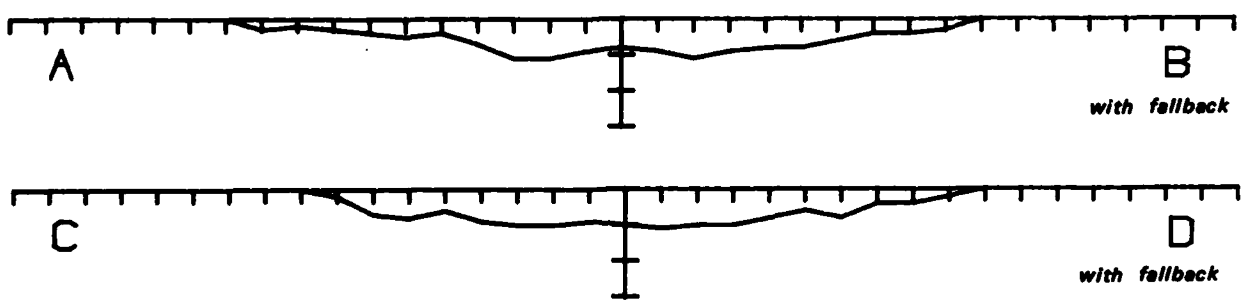


Figure D-26. Crater 17 (Empire Range 6: 105mm).

(Crater 18--see figure D-3.)

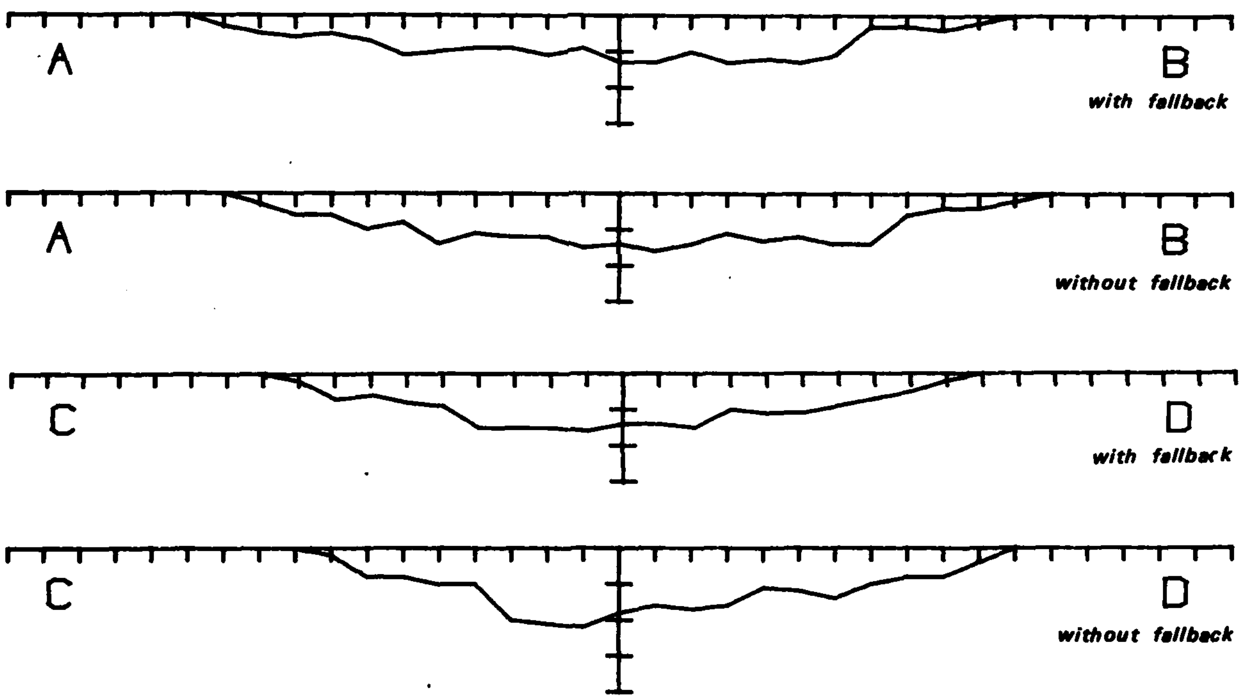


Figure D-27. Crater 19 (Empire Range 6: 155mm).

(Crater 20--see figure D-13.)

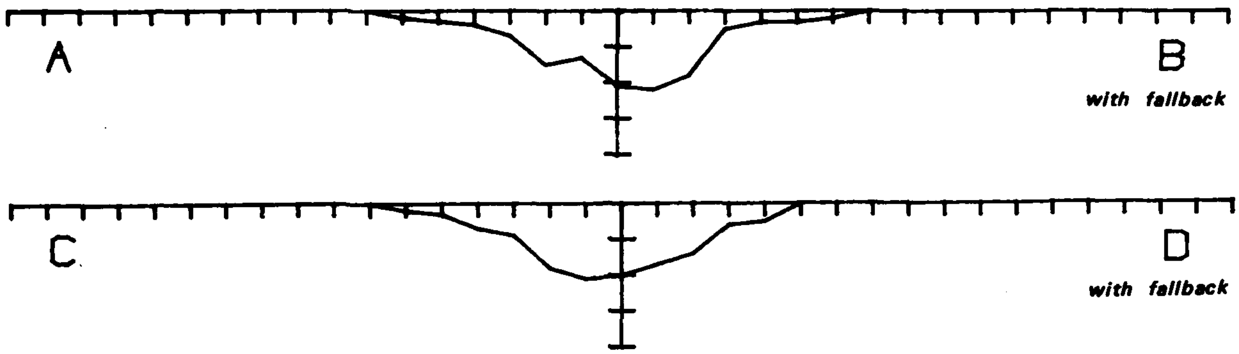


Figure D-28. Crater 21 (Empire Range 6: TNT).

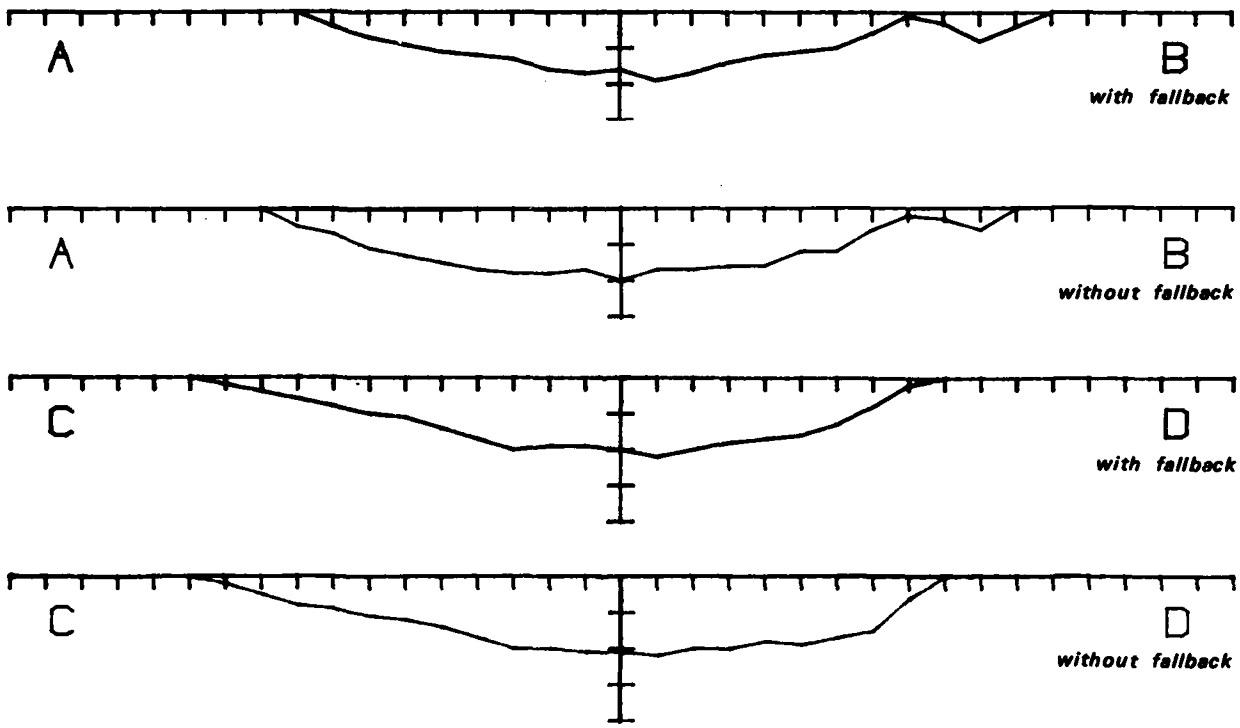


Figure D-29. Crater 22 (Empire Range 6: 155mm).

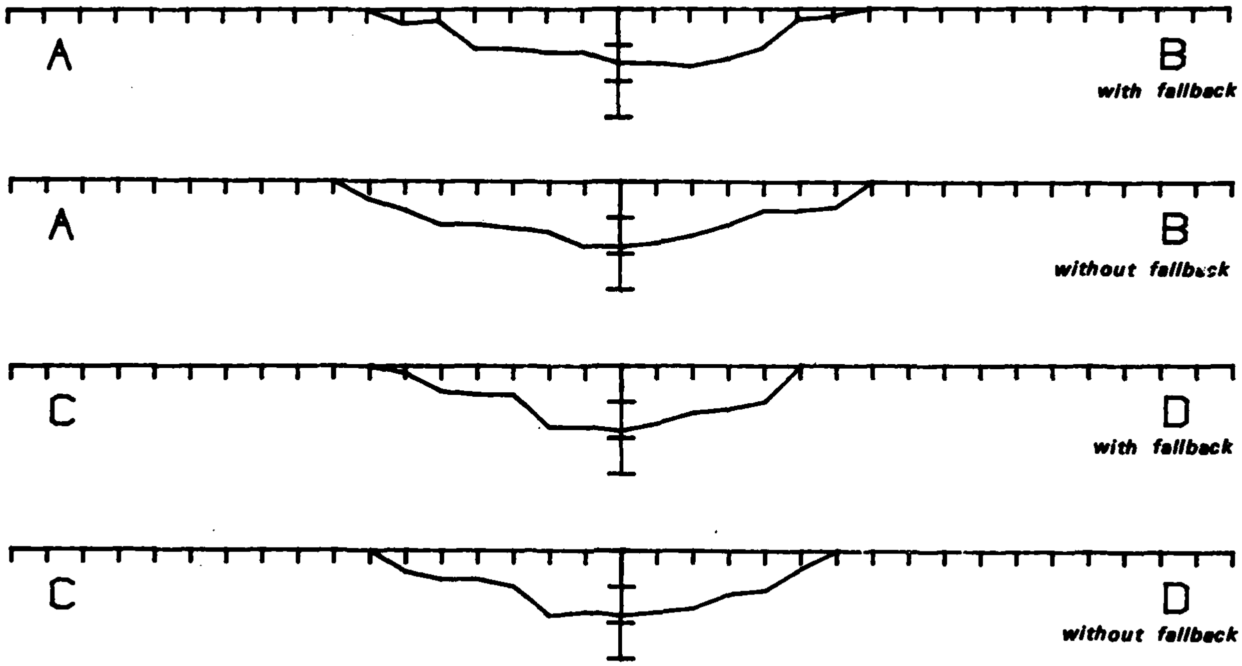


Figure D-30. Crater 23 (Empire Range 6: 105mm.)

(Crater 24--see figure D-14.)

(Crater 25--see figure D-4.)

(Crater 26--see figure D-5.)

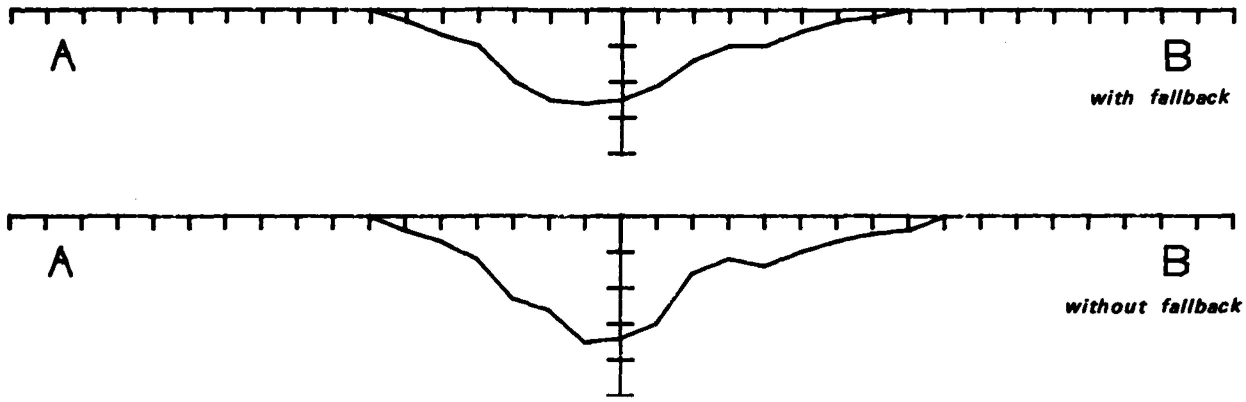


Figure D-31. Crater 27 (Empire Range 6: TNT).

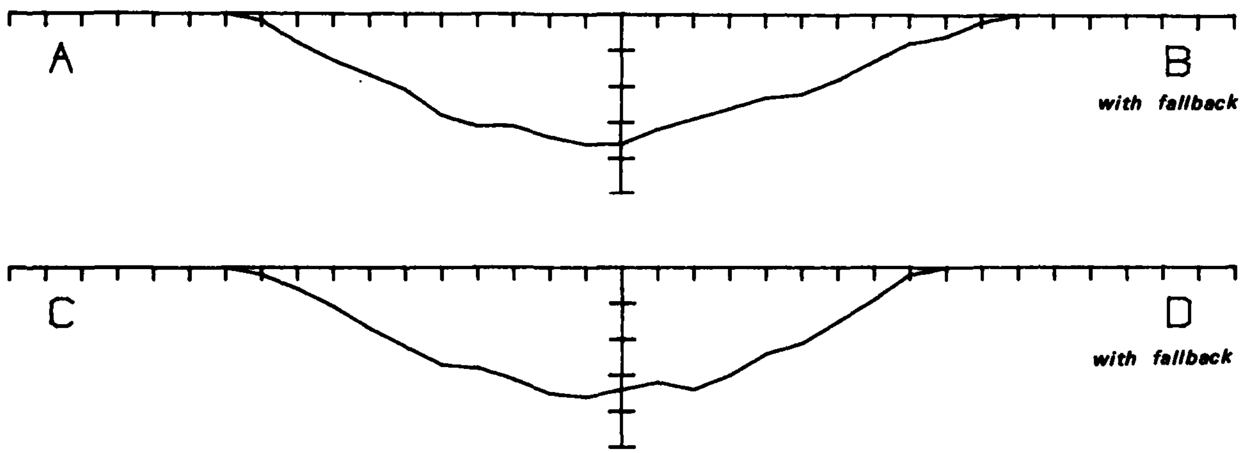


Figure D-32. Crater 28 (Pina Beach: TNT).

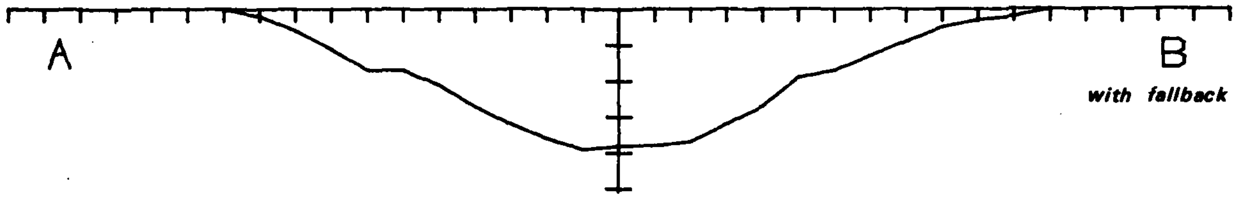


Figure D-33. Crater 29 (Pina Beach: TNT).

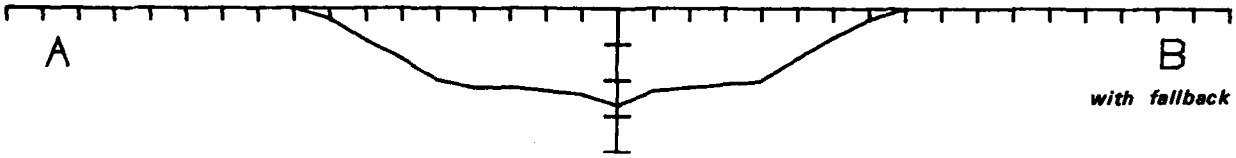


Figure D-34. Crater 30 (Pina Beach: TNT).

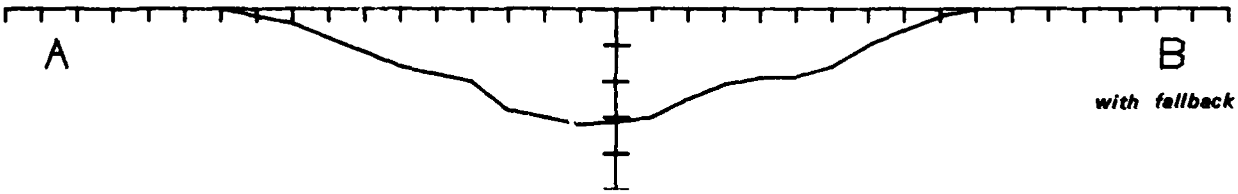


Figure D-35. Crater 31 (Pina Beach: TNT).

(Craters 32 and 33--see figures D-6 and D-7.)

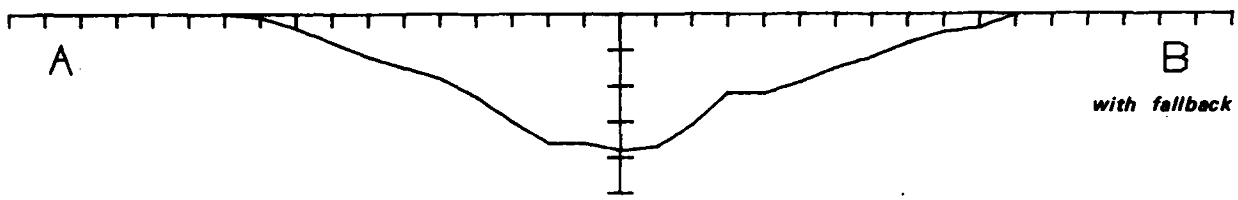


Figure D-36. Crater 34 (Pina Beach: TNT).

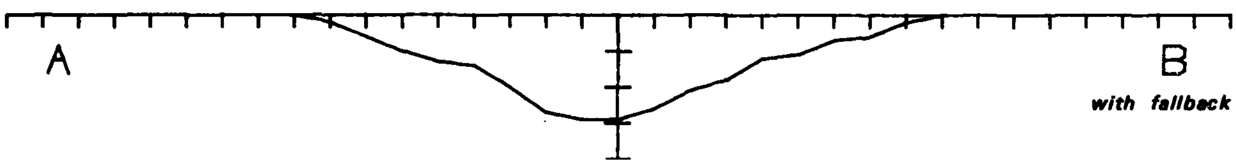


Figure D-37. Crater 35 (Pina Beach: TNT).

(Crater 36--see figure D-8.)

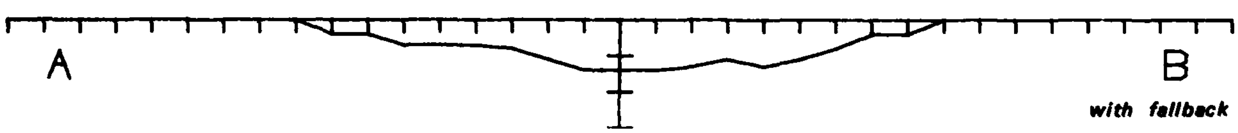


Figure D-38. Crater 37 (Pina Beach: TNT).

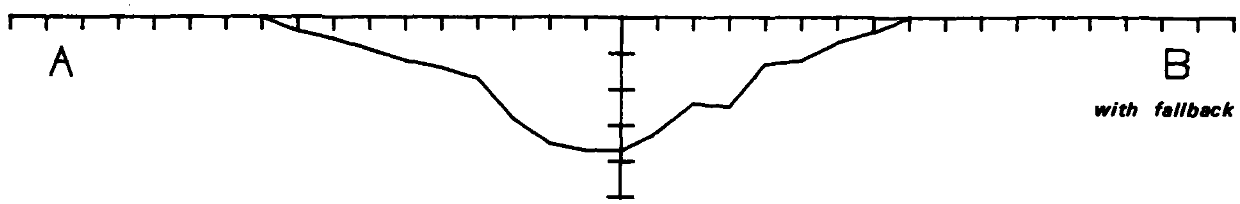


Figure D-39. Crater 38 (Pina Beach: TNT).

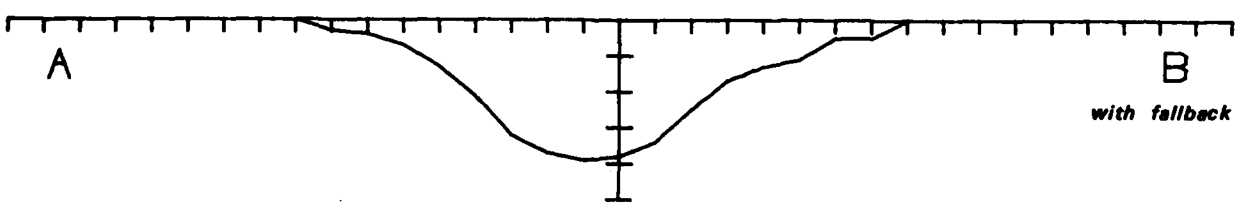


Figure D-40. Crater 39 (Pina Beach: TNT).

Part D-4. Represen-

One Second.

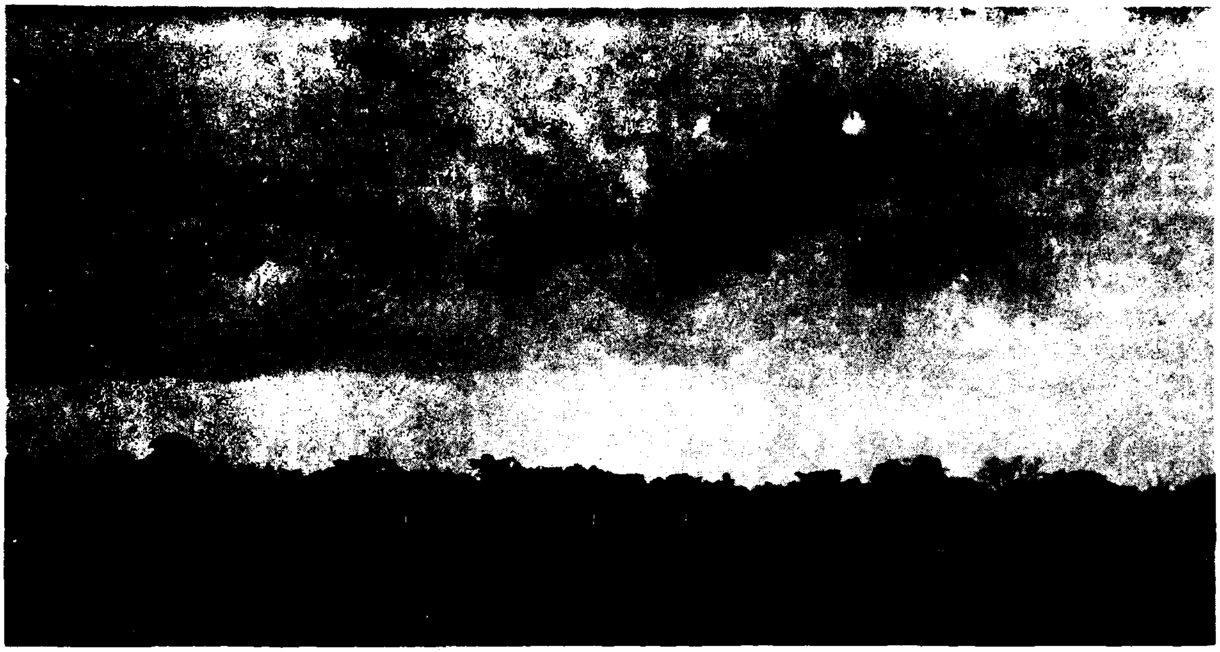
Ten Seconds.

Figure D-41. Cloud from Crater

Five Seconds.

Fifteen Seconds.

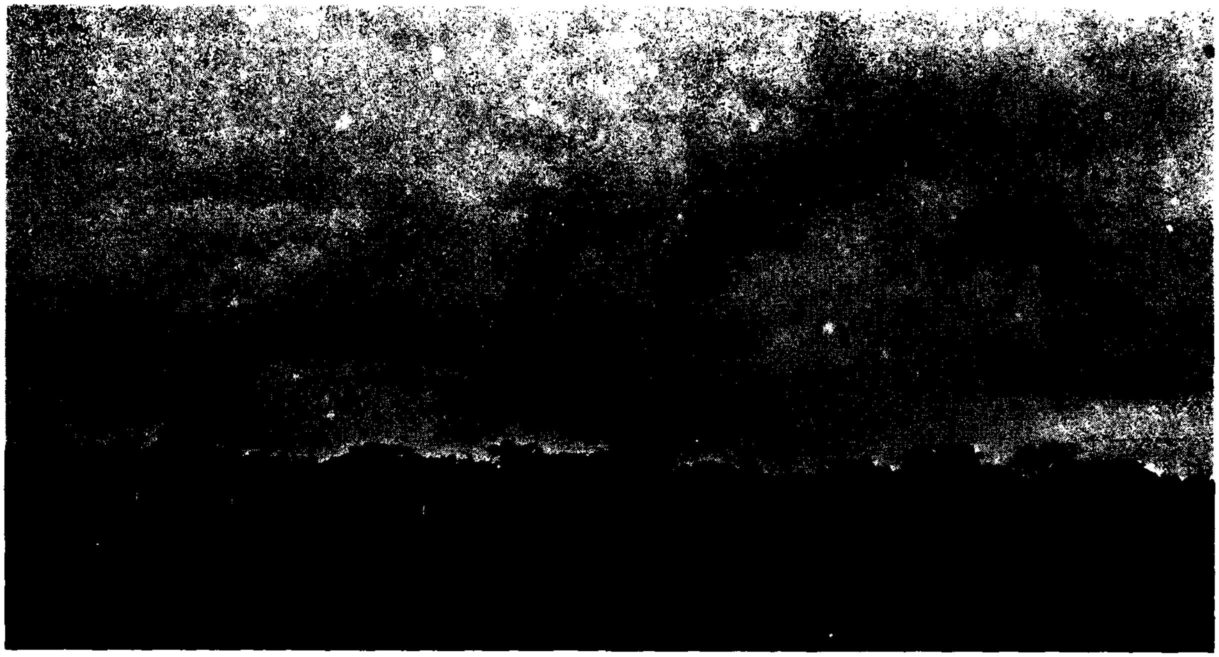
1 at Mindi Farm (155mm).



One Second.

Ten Seconds.

Figure D-42. Cloud from Crater



Five Seconds.

Fifteen Seconds.

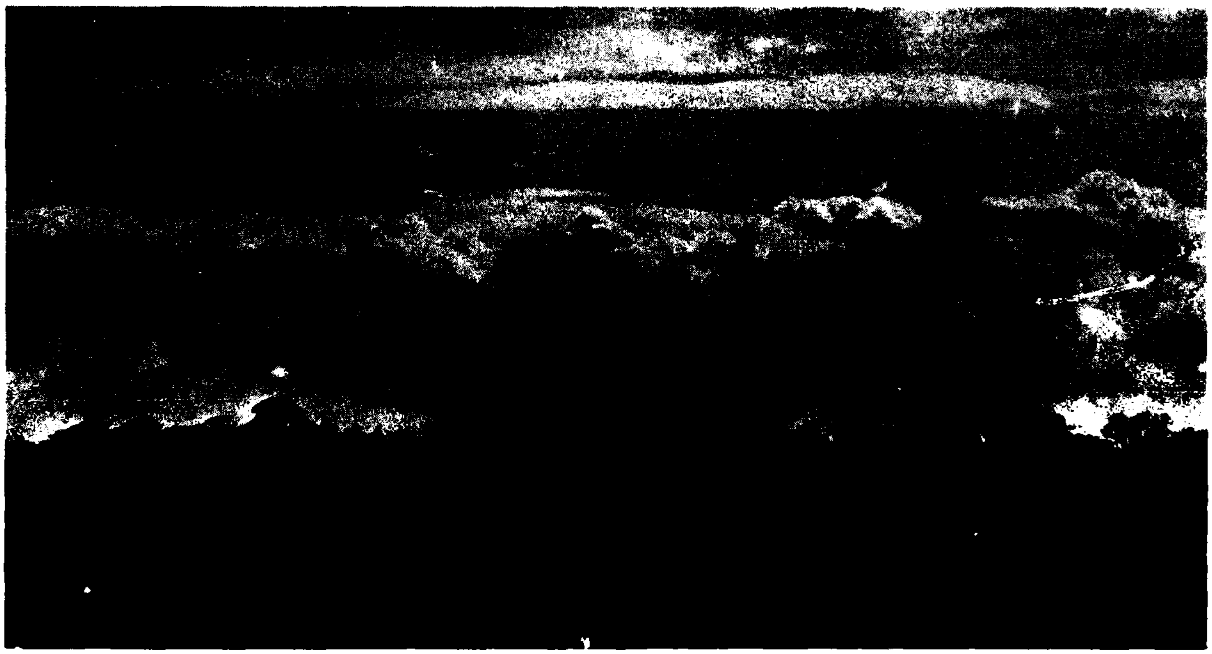
2 at Mindi Farm (105mm).

One Second.

Twenty Seconds.

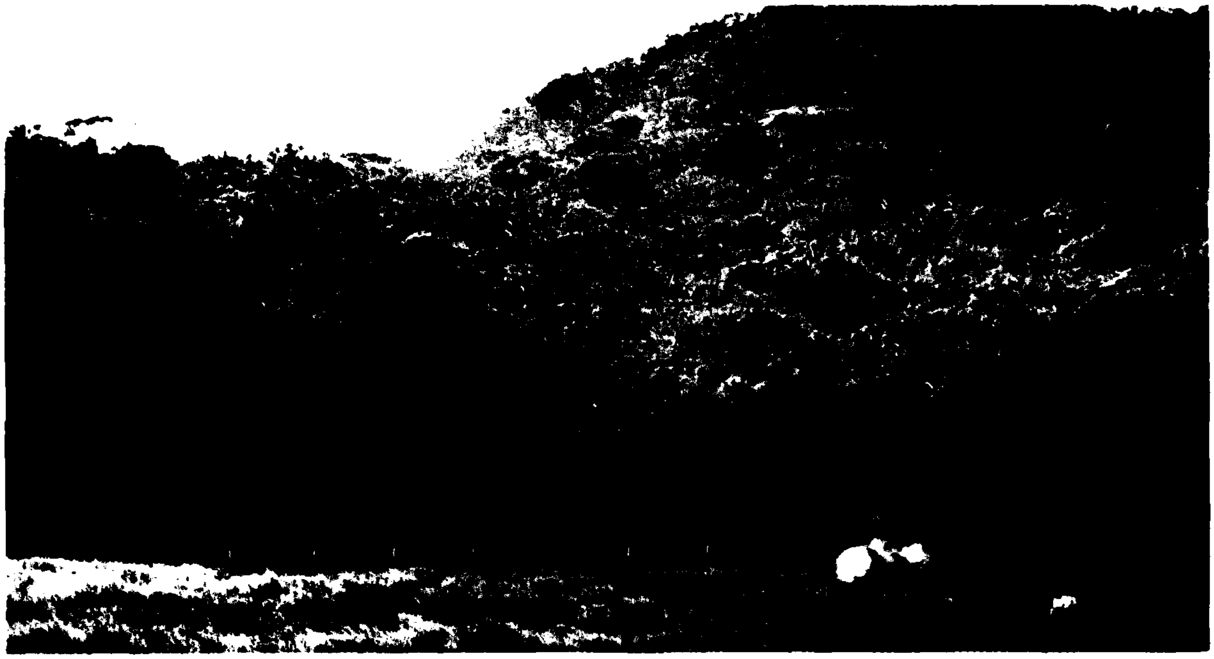
Figure D-43. Cloud from Crater

Ten Seconds.



Thirty Seconds.

6 at Mindi Farm (TNT).



One Second.

Ten Seconds.

Figure D-44. Cloud from Crater

Five Seconds.

Fifteen Seconds.

12 at Empire Range 6 (TNT).

One Second.

Twenty Seconds.

Figure D-45. Cloud from Crater

Ten Seconds.

Thirty Seconds.

16 at Empire Range 6 (155mm).

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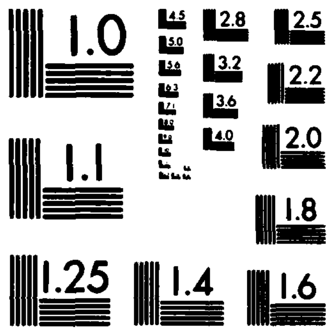


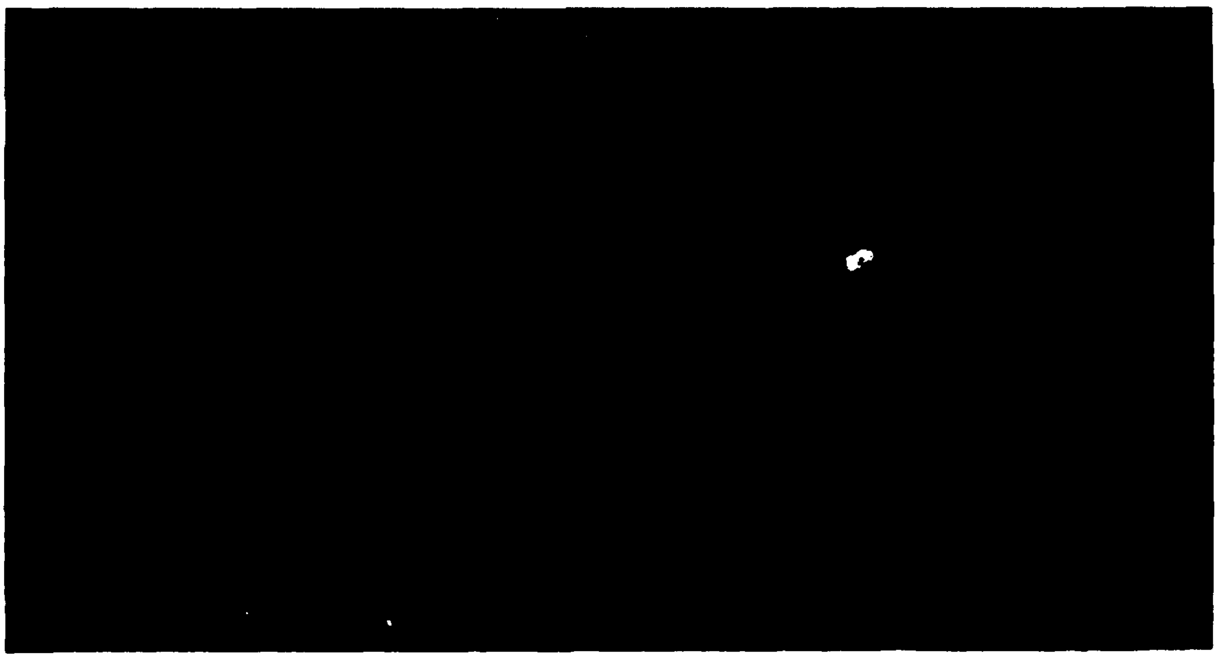
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

One Second.

Ten Seconds.

Figure D-46. Cloud from Crater

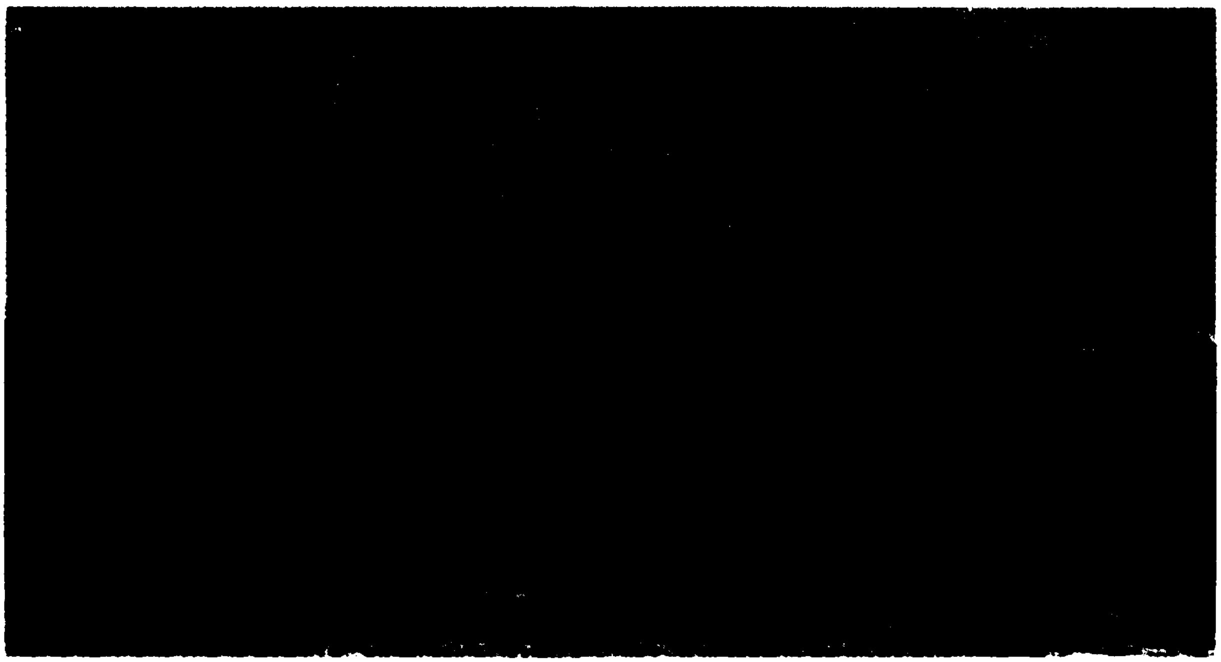
Five Seconds.



Fifteen Seconds.

26 at Empire Range 6 (105mm).

One Second.



Ten Seconds.

Figure D-47. Cloud from Crater

Five Seconds.

Fifteen Seconds.

31 at Pina Beach (TNT).

Part D-5. Selected Crater Profiles from Tube-Delivered Rounds

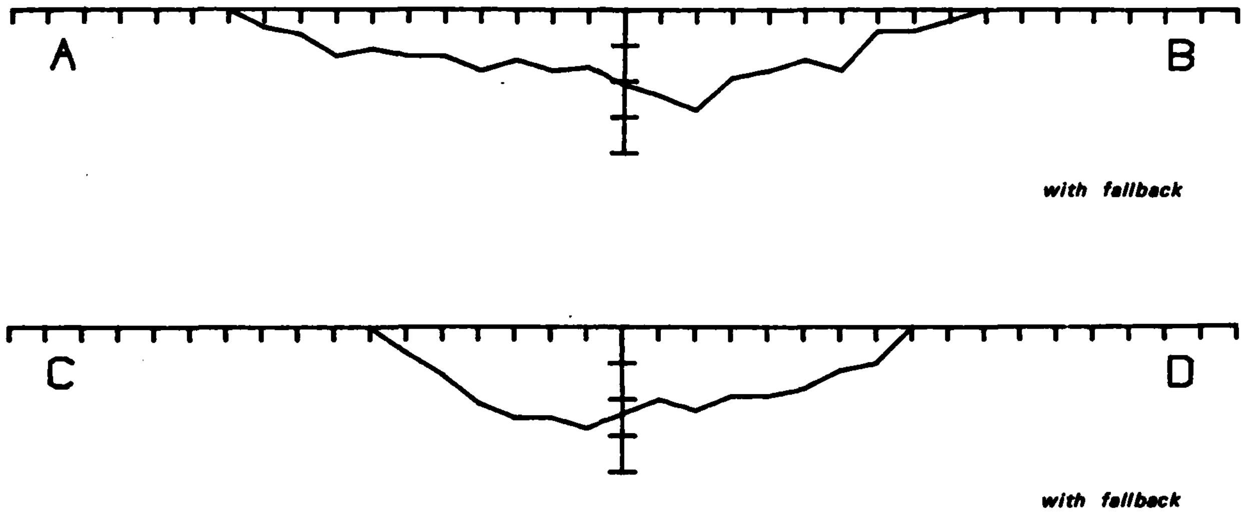


Figure D-48. Crater 42 (Tube-Delivered 105-mm Round: Dry Season).

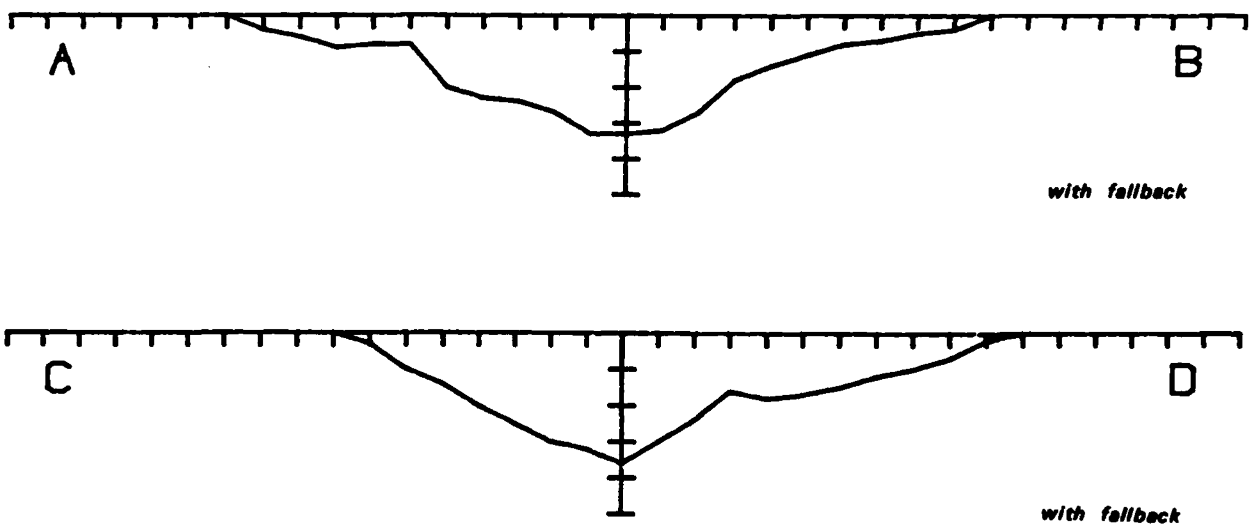


Figure D-49. Crater 46 (Tube-Delivered 105-mm Round: Dry Season).

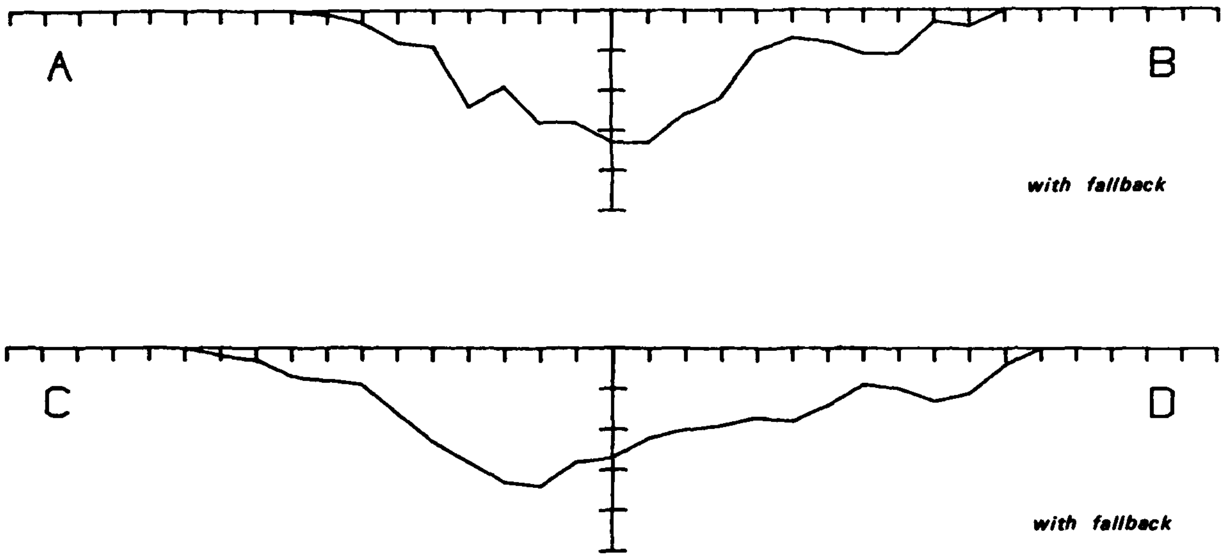


Figure D-50. Crater 48 (Tube-Delivered 105-mm Round: Wet Season).

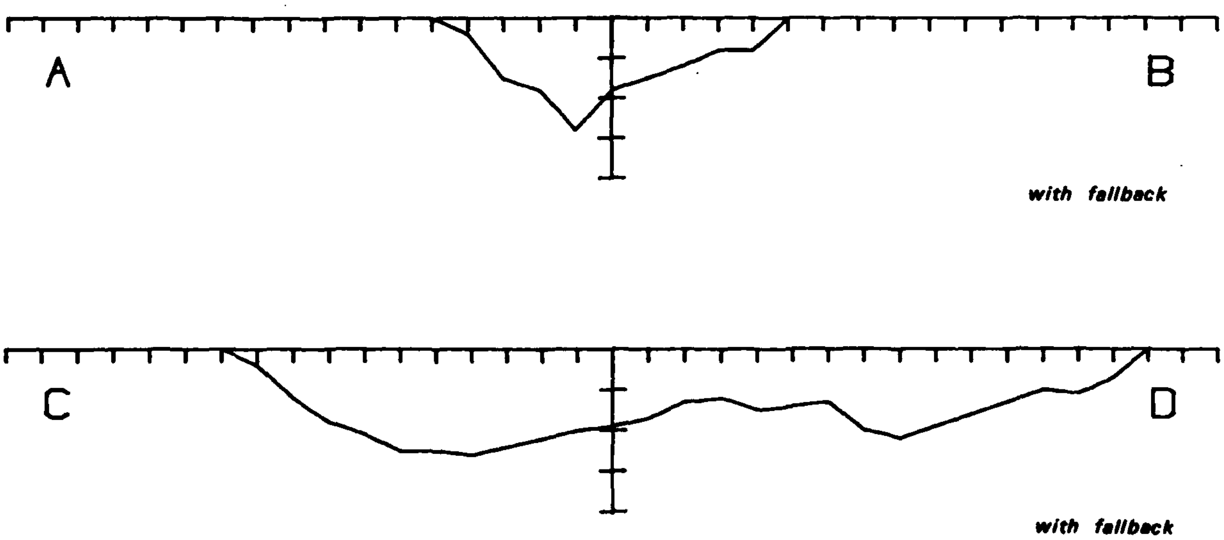


Figure D-51. Crater 50 (Tube-Delivered 105-mm Round: Wet Season).

APPENDIX E. TEST INSTRUMENTATION

1. 1 DM-60 Cubitape, SN 554.

2. Video Instrumentation (configured as shown in figure E-1).

   1 JVC KY2000 3-tube color camera.

   1 JVC KY2700 3-tube color camera.

   2 Pelco pan and tilt heads.

   2 Pelco environmental housings.

   1 JVC RS200U remote control unit.

   1 American Laser Systems model 761 Video Transmission System.

   1 American Laser Systems Remote Control System.

   1 EN500 Honda portable AC/DC generator.

   1 HEI Model 507 time and date generator (0.01/sec res).

   1 Video Date Systems T10245 character generator.

   2 CCHU date bar generators.

   1 ECHO SER special effects generator.

   2 JVC 4400LU 3/4-inch recorder, portable, with AC adapter.

   1 Tektronix 528 wave form monitor.

   2 Sony black and white monitors.

   2 Videotek color monitors.

   1 COHU distribution amplifier.

3. 1 Theodolite surveying instrument.

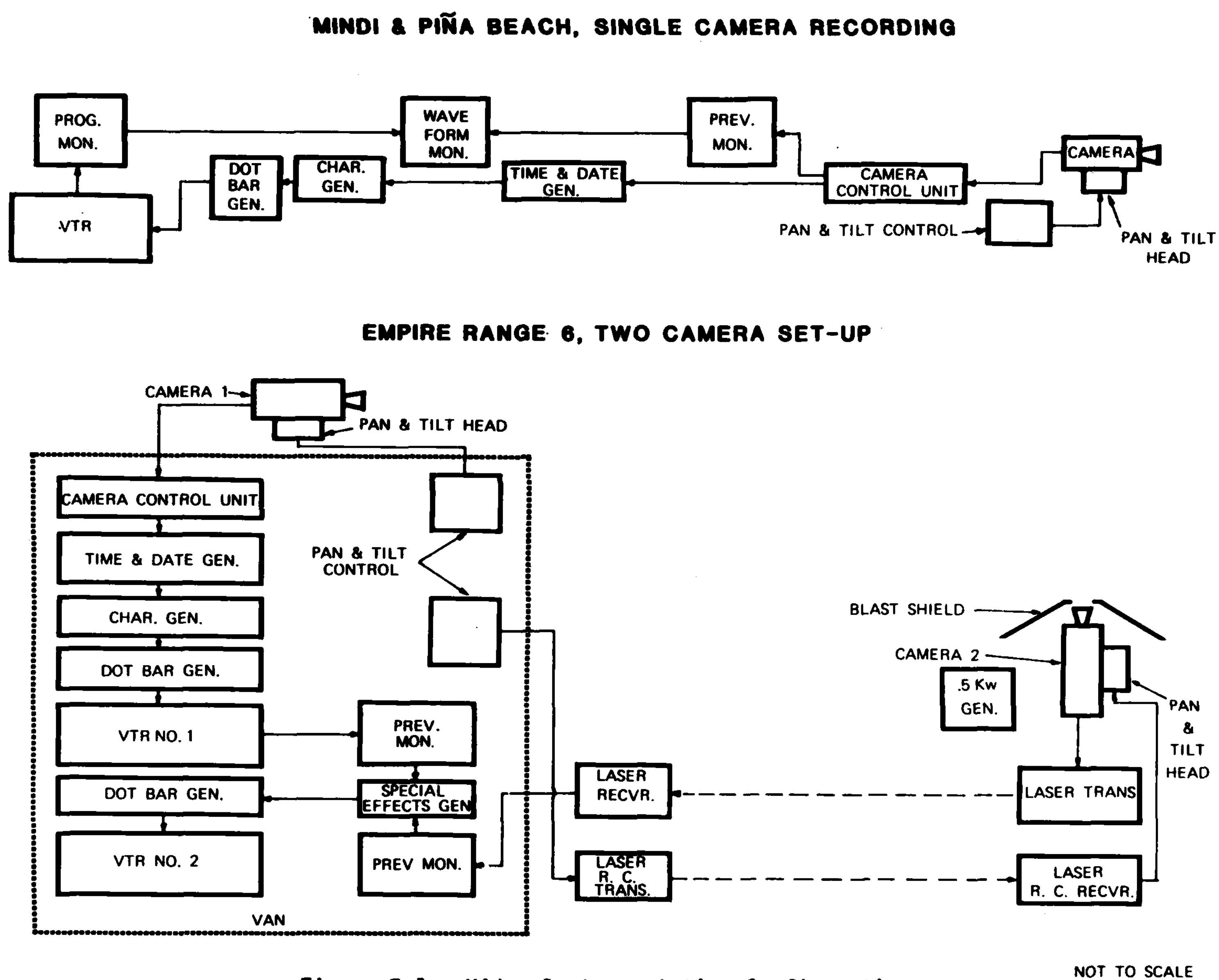


Figure E-1. Video Instrumentation Configuration.

APPENDIX F. REFERENCES

1. Martinucci, Marie T. and Fuchs, Robert J., Final Report, Environmental Realism - Battlefield Obscuration in the Tropics, US Army Tropic Test Center, TECOM Project No. 7-CO-RDO-TT1-004, January 1981.

2. The Chemical Rubber Company Standard Mathematical Tables, 20th Edition, Editor-in-Chief Samuel M. Selby, PhD., ScD, Cleveland, OH, 1972.

3. Department of the Army Technical Manual 5-530/Department of the Air Force Manual 88-51, Materials Testing, February 1966.

4. TOP 4-2-830, Explosive Cratering Tests, 14 May 1980 (Draft).

5. Martinucci, Marie T. and Fuchs, Robert J., Methodology Investigation Plan, Environmental Realism--Battlefield Obscuration in the Tropics, TECOM Project No. 7-CO-RDO-TT1-004, July 1981.

6. SAS Users' Guide, 1979 Edition, SAS Institute, Inc., Raleigh, NC, pp 391 through 392.

APPENDIX G. DISTRIBUTION LIST

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